A SYSTEMS STUDY OF LAMENESS IN DAIRY CATTLE: EFFECTS OF MANAGEMENT, DIET AND BEHAVIOUR

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Abstract

The majority of lameness in dairy herds occurs during the winter housing period when management is at its most intensive. This study assessed the impact of different dietary and management regimes at the system, calving season, and individual level. Observational studies of behaviour and subjective assessment of lameness disease types were carried out on two herds of high genetic merit Holstein-Friesian cows. The herds were housed under identical conditions but differed in their dietary and management regimes. One herd, unit 1, was kept on a low dietary concentrate input regime and milked twice daily in both study years whilst the other herd, unit 2, was fed large amounts of supplementary concentrate over lactation and milked twice daily in year 1 and thrice daily in year 2. Assessment of clinical disease in each unit showed that there were more lameness cases on the high input regime, unit 2; however unit 1 showed a higher incidence of diseases related to claw horn disruption. There was a higher incidence of infectious foot diseases in unit 2, the high input system. The incidence of subclinical lesions in the hooves was influenced by management/dietary treatment: unit 2 animals had more lesions 5-6 months postcalving, however there was no difference between treatments in the early postcalving period or during peak lesion incidence 2-3 months postcalving. This indicated that the increased use of concentrates may have sustained the level of subclinical lesions in unit 2 for a prolonged period. Unit 1 animals fed for significantly longer than unit 2 animals in year 2. Spring calvers on both units spent more time standing within the cubicles. Factor analysis showed that variation in time spent standing and ruminating was mostly influenced by calving season whilst variation in lying and feeding was mostly influenced by dietary treatment. Analysis of the relationship between behaviour and lesions showed that animals which stood for long periods in the cubicles had fewer lesions particularly front foot lesions. There was little effect of lying behaviour on lesion incidence. Further studies investigating aspects of lying behaviour and social interaction at feeding showed that animals with infectious foot diseases would lie down more quickly and lie for longer. The incidence of subclinical disease development was influenced more by management/dietary treatment and calving season than by behaviour which had a small but significant affect on the subclinical development of specific diseases. Decisions on management must take such effects into account if the problem of lameness is to be reduced.

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Contents

1 Introduction: Lameness, its causes and effects

1.1 Background

In a recent report by the Farm Animal Welfare Council - FAWC (Anon, 1997), lameness in cattle is considered to be one of the major economic and welfare problems associated with modern dairy management practices. The economic loss to the producer cannot be easily estimated. Losses arising from reduced condition, compromised milk yield, increased calving interval, increased replacement rate due to culling, treatment and preventative management costs are extremely variable (Dewes, 1978; Collick *et al*, 1989; Esslemont, 1990; Barkema *et al*, 1994; Esslemont & Kossaibati, 1997). Esslemont (1990) estimated a single case of digital disease costs between £130 -180 and Booth (1989) estimated that in the UK lameness accounts for losses totalling £44 million pounds per annum.

The epidemiological and economic studies of lameness have provided an overall assessment of the extent of the problem, which affects between 25-55% of all cattle per year in the UK (Russell & Shaw, 1978; Arkins, 1981; Esslemont, 1990; Clarkson *et al*, 1993; Logue *et al*, 1993; Clarkson *et al* 1996). The exact incidence varies due to precise clinical definitions, geography and year, but it is clear that lameness diseases are far too common in the dairy industry and appear to be increasing over the past 20 years (Esslemont & Kossaibati, 1996).

Once an animal has contracted a clinical disease, she is far more likely to suffer with the same or a related condition in subsequent years. Ultimately, if this effect is extended across all animals, lameness reduces the longevity of the animals due to culling (Esslemont, 1990; Greenough & Vermunt, 1991; Grohen *et al*, 1992; Esslemont & Kossaibati, 1997).

The influence on welfare is clearly apparent; lame animals have increased sensitivity to mechanical stimulus, as defined by a lower threshold to mechanical stimuli, which is a feature of moderate to chronic pain (Ley *et al*, 1996; Whay *et al*, 1997). Lame cows cannot easily cope with their enforced management conditions due to the pain, particularly that associated with movement. Consequently lameness affects an individual's ability to perform normal maintenance activity (Galindo & Broom, 1993).

1.2 Definition

Lameness is a clinical sign of a leg or foot disorder (Greenough, 1991). It can be defined as the expression of aberrant locomotory behaviour due to pain, conformation or paralysis resulting from trauma or disease of the hoof, foot, joint or leg (Ley *et al*, 1994). Unlike in other livestock species, lameness in cattle is primarily localised in their claws and a few specific claw disorders are responsible for 85-95% of all lameness problems (Russell & Shaw, 1978; Logue *et al*, 1993; Peterse, 1987; Zrelli *et al*, 1994). The distribution of areas causing lameness within the limb has varied a little between reports; for example Arkins (1981) showed that 89% of claw horn lesions were associated within the hind feet, and within those hind foot lesions 95% were localised in the lateral claws. Similarly Clarkson *et al* (1993) reported that 92% of lesions occur in the hind feet and 63% of these lesions occur in the lateral claws.

Classification of diseases associated with lameness is complex due to their multifactorial origin. However, a few basic causal categories have been defined (after Peterse, 1987; Faye & Lescourret, 1989):-

Metabolic or non infectious- Due to physiological or biochemical disorders

Traumatic- Due to direct physical injuries to the feet and limbs

Infectious- Resulting from pathogenic attack, e.g. digital dermatitis

Functional- Developmental or genetic basis, e.g. abnormal stance or gait problems

The next section considers types of lameness diseases in more detail, generally following the above classification. Ultimately all of these specific conditions are of multifactorial origin and conveniently categorising them by what is considered to be the most influential causal or risk factor is in fact simplistic. Subsequent sections will cover aspects of management and other factors influencing the risk of developing such diseases.

1.3 Aetiology of the major diseases responsible for lameness

1.3.1 Structure and function of the foot

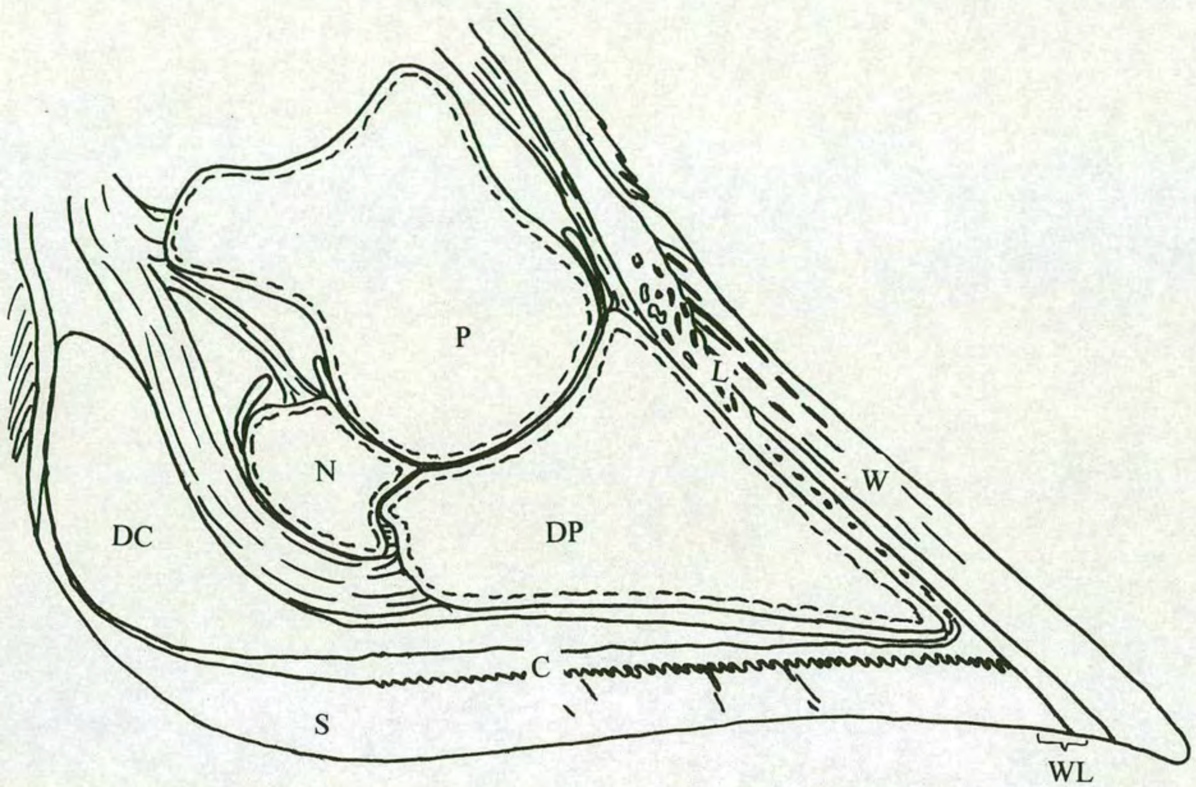
In order to provide the reader with an overview of the descriptive anatomical terms and the function of specific areas of the cow's foot, a very brief explanatory guide follows. All this information is derived from Greenough *et al* (1981) and Greenough & Weaver (1997), should the reader require more detailed information. The skeletal structures within the foot consist of two claws comprising the distal phalanx (pedal bone), the distal part of the middle phalanx, the distal interphalangeal joint and, associated with that joint, the distal sesamoid (navicular bone) (Fig 1.1). The two claws are separated by an interdigital space. Immediately attached to the bones and in some areas almost surrounding them are arrangements of flexor and extensor tendons. Around this is highly vascularised dermis which in the claw, i.e. around the distal phalanx, is further modified in specific areas to form the horn-producing corium. The epidermis of the claw is highly keratinised and forms the horny outer covering often loosely referred to as the hoof.

Beneath the distal phalanx and toward the bulb, the dermis becomes a structure known as the digital cushion (Fig 1.1). The blood vessels in this area are larger in diameter as well as containing considerably more connective tissue than the surrounding dermis. Such modifications enable this structure to function as a "dampener" of downward force during movement and also as a remote "pump" for the circulatory system in the foot.

The claw horn itself can be conveniently separated into three distinct areas of horn: wall, sole and bulb or heel (Fig 1.2). As mentioned previously the horn is made of a modified superficial layer and is continuous. At the top of the claw there is an abrupt transition between the hoof and the skin called the coronary border or coronet. The wall horn is the primary weight-bearing area for the underlying skeletal structures. In the lower part of this area the corium is convoluted so that it produces horn which is fluted or ridge like. This area is referred to as the lamina corium and horn and provides the major weight-bearing point between the claw horn and the distal phalanx. The horn of the wall meets the horn of the sole at a junction called the zona alba or white line. This area consists of modified horn -

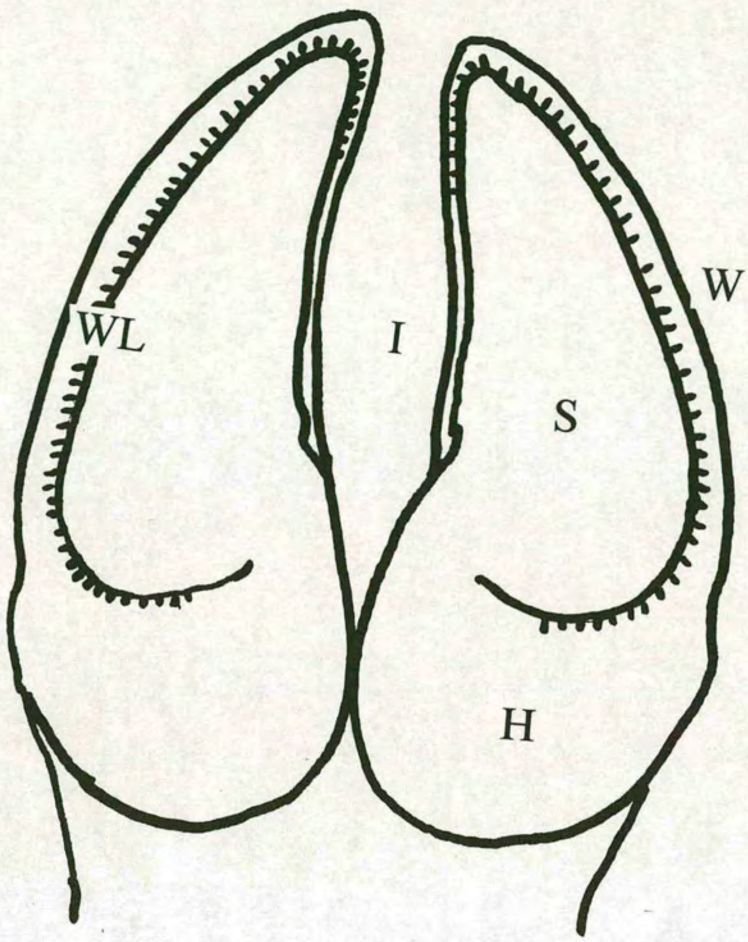
"interdigitating horn" which can withstand the stresses developed between the sole and wall areas during locomotion.

Fig 1.1 Diagram of a sagittal section through the claw



Key: **C** Corium; **DC** Digital cushion; **DP** Distal phalanx; **L** Lamina corium; **N** Navicular bone; **P** 2nd phalanx; **S** Sole horn; **W** Wall; **WL** White line

Figure 1.2 Regions of the hoof



Key: **H** Heel; **I** Interdigital space; **S** Sole; **W** Wall; **WL** White line.

1.3.2 Laminitis (Pododermatitis aseptica diffusa)

Laminitis is considered to be the disease linked to most lameness cases in the UK (Blowey, 1985; Bradley *et al*, 1989; Logue *et al*, 1993) and has sporadic prevalence (Ebeid, 1993). Signs include incorporation of haemorrhages into the hoof horn, degenerative changes in the claws and a softening or widening of the white line area (Ebeid, 1993; Singh *et al*, 1993b). Recently this condition was sub-divided into the following distinct categories:- chronic, acute, sub-acute and sub-clinical (Vermunt & Greenough, 1994). "Laminitic" lesions are generally (but not universally) considered to be a result of metabolic dysfunction rather than direct trauma (Bradley *et al*, 1989) but there are many additive factors that contribute to disease development and severity. The disease is believed to arise from a disruption of the blood supply to the vascular horn-producing region of the hoof - the corium. Vermunt and Greenough (1994) suggest that arteriovenous anastomoses occurring in response to certain vasoactive substances, blood pH or trauma shunt the blood from the corium. The underlying mechanism which triggers this process has yet to be identified: whether it arises from rumen dysfunction, raised endogenous histidine levels or other factors remains unclear. Once the process has been triggered the blood stagnates causing increased pressure and pain. Oedema is often seen as fluid leaks into the tissues (Greenough, 1991; Singh *et al*, 1993b; Ossent & Lischer, 1994) and further damage due to hypoxia is common. This damage leads to capillary breakdown and eventually haemorrhages form within the horn. Severe laminitic damage can lead to rupture of the linkage between the pedal bone and lamina and consequently this bone irreversibly sinks downward towards the sole. The changed pedal bone position often increases the risk of laminitis as it traps blood vessels particularly in the sole corium leading to a number of lesions associated with lameness (Ossent *et al*, 1997).

Fragments of damaged corium and epidermis are incorporated within the haemorrhages, these areas being particularly susceptible to infection and often becoming necrotic (Ossent & Lischer, 1994). Claws affected by chronic laminitis are often characteristically flat and wide (Bradley *et al*, 1989), and the hoof horn may have a yellow, waxy appearance (Greenough & Vermunt, 1991; Vermunt, 1992; Ebeid, 1993).

Sole haemorrhages are general lesions originally occurring in the corium of the sole. Their position depends on a number of factors; angle and configuration of the pedal bone, conformation of the claw and uneven growth and wear (Ossent *et al*, 1997). They are characterised by lines or blotches of pink or reddened horn tissue (Greenough & Vermunt, 1991). A reduction of the integrity of the junction between the wall and sole due to laminitis results in white line lesions; this may be associated with rotation of the distal phalanx and in severe cases toe ulcers can form (Mortensen, 1994).

1.3.3 Sole bruising (Aseptic traumatic pododermatitis)

Bruising of the soles is a common condition seen in heifers when introduced onto concrete (Greenough & Vermunt, 1991); afflicted animals characteristically have a very stiff-legged gait (Baggot & Russell, 1981; Blowey, 1985). The bruising is characterised by soft mottled areas of the sole (Blowey, 1985), which can be sensitive but rarely cause severe lameness (Arkins, 1981). In appearance this disorder is clearly closely related to laminitis, however the risk factors have a traumatic and metabolic origin. Sole bruising has also been associated with traumatic damage from stones on rough walkways (Arkins, 1981, Baggot & Russell, 1981), and also from rapid weight gain leading up to calving in heifers (Greenough & Vermunt, 1991).

1.3.4 Sole ulcer (Pododermatitis circumscripta)

Ulceration of the sole is described as a contusion of the corium with interrupted horn formation (Toussaint-Raven, 1985), and appears as a circumscribed necrotic area (Singh *et al*, 1993b). The disease predominantly affects the lateral hind claws (Arkins, 1981; Clarkson *et al*, 1993); but its exact aetiology and development is unclear although it is closely associated with laminitis (Greenough & Vermunt, 1990; Enevoldsen *et al*, 1991a; Ebeid, 1993; Singh *et al*, 1993b; Ossent *et al*, 1997). It results from convergence of an underrun area with severe sole haemorrhaging, typically occurring at the heel/sole junction. Sole overgrowth is also implicated, as this shifts the weight-bearing area onto the sole (Livesey & Fleming, 1984; Toussaint-Raven, 1985), resulting in bruising and poor quality horn formation in this area (Blowey, 1985; Ossent & Lischer, 1994). Over time the haemorrhage site weakens with a sinking or outward growth of the tissues and a thinning of the sole horn to the point of corium exposure. Once this occurs, bacteria penetrate the underlying softer tissues and infection can travel through the claw (Baggot & Russell, 1981). In serious cases the immediate tendons and ligaments of the pedal and navicular bones are infiltrated, causing extreme pain in the foot (Blowey, 1985; Singh *et al*, 1993b; Collick, 1997). If sole ulcers are not treated by "pressure relief" trimming or by applying a block to the inner claw to raise the affected claw, irreparable damage occurs, prolonging pain and injury to the animal (Livesey & Fleming, 1984; Toussaint-Raven, 1985). Once affected, the site of sole ulcer development appears to be at future risk, as the area is weakened and susceptible to erosive and metabolic damage, seriously threatening the productive life of the animal.

1.3.5 White line disease and septic penetration (Pododermatitis traumatica)

White line disease is described as underrunning or penetration of the white line area to the corium on the distal surface of the claw at some point along its abaxial border (Singh *et al*, 1993b). The area usually appears regularly eroded and is open to invasion from particulate detritus. This lack of integrity of the white line is believed to be related to laminitis (Baggot & Russell, 1981; Livesey & Fleming, 1984) and rightly so as laminitic lesions are often present prior to this disease and in the corresponding white line areas. Pieces of stone penetrate the weakened area of the white line causing a further loss of integrity and carrying bacteria which can infect the laminae (Baggot & Russell, 1981; Collick, 1997). Infection spreads along the line of least resistance causing inflammation and placing pressure on the wall/sole junction. These incidents are far more common in the summer, indicating that walking along tracks is possibly a major risk factor for this specific disease (Murray *et al*, 1996). An afflicted animal is in severe pain and in extreme cases the abaxial wall may separate completely (Collick, 1997) at which point the damage is often irreparable unless the animal is provided with an extended recuperation period at pasture.

1.3.6 Heel erosion (Erosis ungulae)

The heel is the shock-absorbing area of the hoof during the initial weight-bearing phase of the step (Greenough *et al*, 1981). Erosion of this area of softer horn is often seen in housed cattle during winter (Murray *et al*, 1996) but is rarely a direct cause of lameness (Arkins, 1981). The disease has multifactorial aetiology but generally it is a two-stage process (Toussaint-Raven, 1985). The initial stage involves infection of the epidermis by bacterial or chemical agents and the deformation and destruction of the horn; characteristic 'V' shaped fissures may develop (Arkins, 1981; Collick, 1997). The secondary stage involves abnormal horn formation, altering the weight bearing areas of the foot (Baggot & Russell, 1981; Collick, 1997). The fissured defective horn provides an opportunity for secondary infection by pathogenic microbes (Greenough *et al*, 1981; Toussaint-Raven, 1985; Collick, 1997), and has been linked with the presence of interdigital dermatitis (Enevoldsen *et al*, 1991b).

1.3.7 Foul in the foot (Phlegma interdigitalis)

This disease is thought to start with the susceptible interdigital area picking up small objects such as rocks, rough grass or bedding which abrade the surface of the skin. These minor wounds then become deeply infected by the bacterium *Fusobacterium necrophorum* (Baggot & Russell, 1981; Greenough *et al*, 1981).

The subcutaneous tissue between the claws is then subject to severe swelling (Toussaint-Raven, 1985; Bergsten, 1997), which pushes the claws outward and causes the animal severe pain during standing (Greenough *et al*, 1981; Bergsten, 1997). The disease is prevalent during the housing period and also during the summer months when the warmer temperatures promote bacterial growth (Enevoldsen *et al*, 1991b). Parturition and associated management and nutritional changes at this time appear to be important as the incidence of this disease in Danish herds is six times higher in the first month post-partum than in any month pre-partum (Alban *et al*, 1995).

1.3.8 Interdigital dermatitis (Dermatitis interdigitalis)

This condition differs from foul in that the bacterial infection does not penetrate the basement membrane resulting in deep fissures but causes painful inflammation of the interdigital skin. The skin's surface is typically eroded and there may be associated hypertrophy as a response to invading bacteria. The bacteria primarily responsible are *Bacteroides nodusus* which attack weak skin areas (Toussaint-Raven, 1985) but recent work by Van Amstel & Bemis (1998) has shown that spirochaetes are commonly found within affected interdigital tissue, suggesting the disease could be related to digital dermatitis. The disease is associated with warm humid environments presumably as these conditions promote bacterial proliferation.

1.3.9 Digital dermatitis (Dermatitis digitalis)

This disease is generally characterised by infection and inflammation around the heel bulb, coronet and accessory digit area (Mortellaro, 1994); hypertrophy and hyperplasia thickening the epithelial layer is also common (Bergsten, 1997). Superficially the disease is similar to interdigital dermatitis and there is some discussion whether it is a separate disease. Spirochaete bacteria from cases of the two diseases have been isolated and are morphologically and antigenically identical (Walker *et al*, 1995). Lesions of this type appear quickly and are extremely painful when touched (Toussaint-Raven, 1985); complications due to other disorders such as heel horn erosion and heel underunning are common (Amstel *et al*, 1995). In a study reported by Murray *et al*, (1996) digital dermatitis was found to be the most common infectious disease and was closely associated with winter housing.

1.4 Methodology of lameness study

Work on lameness has employed many varied study techniques. However the majority are based on epidemiology discipline which aim to study lameness disease in a given or defined population and the factors that determine its occurrence. Epidemiological techniques can range from basic surveillance to complex multifactorial modelling of specific diseases. The majority of epidemiological work in the lameness field has taken the form of observational studies or surveys looking at the major disease parameters, namely incidence and prevalence. Incidence is defined as the number of new cases that occur in a known population over a specified period of time; this can be used to provide a cumulative incidence of disease which takes into account the proportion of non diseased individuals that will contract the disease over the study period - it can be roughly defined as "risk" (Halpin, 1975; Thrusfield, 1995). Prevalence is an instantaneous measurement of a disease, defined as the numbers of instances of a certain disease in a known population at a designated time without distinction between old and new cases (Halpin, 1975; Thrusfield, 1995).

Epidemiological surveys are general investigations usually involving comparison of groups of animals. They are relatively simple to conduct but rely heavily on adequate records and measurement techniques that are repeatable by different observers (Martin *et al*, 1987). Alongside surveys there are three main study methods which can be employed: Cross-sectional, case-control and cohort studies. The former two study methods are broadly concerned with determining the causal factors of the disease whilst the last is concerned with the calculation of disease risk in a population as defined by exposure to causal factors (Martin *et al*, 1987; Thrusfield, 1995). Each type of study has its advantages and disadvantages, as follows.

Cross-sectional studies investigate the relationship between presence or absence of a disease in a known population. They have advantages in that they are (relatively) quick to conduct and allow the study of multiple interwoven possible disease causes. However it may be difficult to determine whether factors are causes or effects, and problems may arise from inability to control extraneous variables (Martin *et al*, 1987; Thrusfield, 1995).

Case-control studies compare healthy and diseased animals in a population with reference to exposure to hypothesised causal factors. This method also allows investigation of multiple causal factors but validation of collected information is difficult because of lack of extraneous variable control. In addition, selection of appropriate comparison animals is often difficult (Halpin, 1975; Thrusfield, 1995).

Cohort studies involve selecting groups of animals from a larger population and comparing groups that are exposed or unexposed to causal factors, with reference to the development of the disease. This method is highly flexible and can deal with additive interactions in a number of situations. However, large numbers of subjects, a long follow-up duration and extremely repeatable measurements are required (Halpin, 1975; Thrusfield, 1995).

All these types of study, although (relatively) easy to conduct are expensive in terms of finance and/or labour.

The most widely used alternative to epidemiological studies of causal or risk factors is experimental studies where the investigator allocates animals to various groups according to the factors to be investigated. Subjects are balanced as far as possible to remove residual variance due to extraneous factors. The advantage of this method is that control allows extremely detailed investigation of specific factors, but such studies are often expensive or limited in effectiveness because of small sample sizes.

Method of study depends primarily on the investigator's objectives within a financial and logistical framework. However most lameness studies are often conducted on working farms, not designated research facilities, so goals have to be realistic, taking the detailed circumstances into account.

1.5 Developmental and risk factors responsible for lameness

1.5.1 Age and parity

Age and parity are risk factors associated with lameness (Russell *et al*, 1982; Harris *et al*, 1988; Grohen *et al*, 1992; Wells *et al*, 1993a), and the distribution of specific diseases across age and parity categories varies. Greenough & Vermunt (1991) reported that incidences of laminitis were significantly higher in first calving heifers than in multiparous cows. However their data was based on subclinical observations. Furthermore, there was a greater range of lesion scores in the second parity and older animals; in fact the second parity animals had some of the highest individual scores in the study groups together with a significantly higher incidence of sole ulcer. Generally a higher prevalence of clinical lameness is associated with higher parity cows (Smits *et al*, 1992; Wells *et al* 1993a). This situation is not clear because these studies have concerned cattle that are either housed the whole year round or have only a brief time at pasture, increasing the age related risk compared to cattle that are able to recover from lesion damage at pasture. One possible explanation of age conferring added risk is that claw lesions in older animals heal more slowly due to corium scarring from previous lesions, therefore the effects of a longer term disease are more obvious in these older animals (Greenough & Vermunt, 1991). Overall there is a cumulative risk of becoming lame with each lactation year for housed cattle (Grohen *et al*, 1992). Hind feet are particularly susceptible to lesions at two years of age (Dewes, 1978). Bergsten (1994) showed epidemiologically that primiparous cows are more prone to sole haemorrhages than multiparous cows.

A similar pattern in disease incidence between heifers and multiparous cows is seen with interdigital dermatitis (Enevoldsen *et al*, 1991b). These correlative factors are confusing, as heifers are exposed to major management and nutritional changes from which the effect of age alone cannot easily be separated. Heel erosion is more common in mature animals (Enevoldsen *et al*, 1991b; Tranter *et al*, 1991), presumably due to the increased exposure to pathogenic bacteria within the housed environment through each housing period. However on pasture the heel horn recovers quickly. Therefore provided the length of time spent at pasture is sufficient, and the lesions developed in the previous housing period were not severe enough to expose the corium, the risk of heel erosion should be similar each year.

1.5.2 Body weight

There have been few studies on the association between larger body size and incidence of lameness. Holsteins and other heavy breeds are far more likely to suffer from lameness diseases (Chesterton *et al*, 1989) but the influence of genetics susceptibility is probably a greater factor than liveweight alone. A study by Wells *et al* (1993b) found a strong positive correlation between body weight and cases of clinical lameness. Body weight is important as sole ulcers occur in areas of the foot supporting greatest pressure, so if the weight bearing surfaces of the sole were abnormal a heavier body weight would lead to increased pressure in certain areas and thus increased risk of sole ulcer (Enevoldsen *et al*, 1991a). Baggot & Russell (1981), using data from an earlier Compton lameness survey, reported that sole ulcers were more common in older animals than heifers and were most common in "medium" size animals of about four years of age. Presumably though, they are less common in animals over 4 years of age simply due to the fact that sole ulcer problems are one factor contributing to the decision to cull older animals. The apparent paradox between the distribution of weight between front and hind claws and the distribution of lesions was partly resolved by force plate studies. Although when standing the front claws carry more weight, during locomotion considerably more propulsive or accelerative force is passed through the hind claws (Scott, 1989). Such forces may be more important in the development of lesions, partly explaining the predominance of lesions in the hind claws.

There may be an influence of scaling of selected traits, in that selection for size in modern dairy breed may not have resulted in an isometric increase in hoof dimensions. That is to say, for example, that a 5% increase in body weight has not led to a proportional increase in claw area to maintain comparable force per unit area on the foot. Breeds selected for increasing yields are increasing in size; they may therefore have increased weight per unit area of hoof surface, exacerbating the risk of lameness.

In the UK the index of total economic merit (ITEM) used in Holstein-Friesian selection has type traits incorporated into the calculation matrix (Simm *et al*, 1995). These type traits are thought to influence longevity and include hoof angle, but inclusion of this trait is misleading as hoof angle is greatly influenced by regular trimming. It is entirely possible that herds with optimal hoof angles for selection are not genetically disposed to express this trait but rather are managed with more frequent preventative foot trimming.

1.5.3 Calving date and stage of lactation

The effect of calving date and stage of lactation are difficult to resolve in terms of aetiology, due to confounding factors such as housing, calving itself and nutritional changes (Greenough 1994). Cattle are far more sensitive to environmental and nutritional risk factors postpartum (Bergsten & Frank 1996a;b). The post calving/early lactation period is evidently crucial for the animal, as development of lameness-causing diseases is more likely at this time (Baggot & Russell, 1981; Alban, 1995; Jubb & Malmo, 1991; Bergsten & Frank, 1996b). Sole haemorrhages, ulcers and other diseases often peak around this transition period (Dewes, 1978;

Bradley *et al*, 1989; Enevoldsen *et al*, 1991a,b; Tranter *et al*, 1991; Ebeid, 1993; Kempson & Logue, 1993; Brandejsky *et al,* 1994). Nilsson (1963) describes this peak as "parturition laminitis", suggesting that histamine produced by retained placental tissues in the uterus causes corio-vascular disorders. However, Boosman (1980) was unable to reproduce this effect by administering subcutaneous or intravenous histamine. Bazeley & Pinsent (1984) Have attributed the rise in lesions post calving as a response to the increased metabolic demands approaching peak yield. A combination of the above and other factors probably occurs.

1.5.4 Genetics

Certain breeds of cattle have long been known to have fewer lameness problems. Swedish red and white cattle are far less likely to be affected by laminitis than Friesians (Bergsten, 1994; Mortensen, 1994) and there is much anecdotal evidence in Scotland for decreased lameness incidence in Ayrshire cows. From a conformation viewpoint, lameness could be exacerbated by certain heritable traits such as straight hind limbs or high intake capacity (Vermunt & Greenough, 1994). In a study of genetic traits in Holstein-Friesian cattle, Boelling & Pollott (1995 a,b) reported that animals with steeper foot angle, straighter legs and high udders had better mobility. The apparent disagreement on the effects of straight limb conformation is probably due to contrasting viewpoints on the same problem. Selection schemes that incorporate leg conformation traits alongside selection for higher individual milk yield will see an associated rise in the incidence of lameness due to increased metabolic demand and other production factors which will also correlate positively with straighter limbs. Contrastingly, in the work of Boelling & Pollot (1995 a) which measured mobility and various physical aspects of an animal's leg and claw, it could be seen that straighter limbs improved gait by increasing stride length. Therefore improved mobility is a function of the possession of straighter legs. Therefore by selecting for mobility, straighter leg traits would also be selected for, and, if this were the case, then it is not suprising the conclusion that straight legs were a beneficial trait was reached.

Hoof shape and amount of pigment within the hoof horn is hereditary. The latter may be relevant because Chesterton *et al* (1989) concluded that black hooves were harder and more resistant to abrasion and were associated with less lameness. However, in his study, herds with a large percentage of black hooves also had increased proportions of Jersey cattle. Jersey type cattle show less lameness problems in comparison to Friesians (Logue et al, 1994). Logue *et al* (1994) found no significant difference between black hooves and white hooves in terms of hardness although hooves with black bands in them had fewer but not significantly fewer lesions. Poor hoof shape is associated with a high degree of lameness (Clarkson, 1993) and in addition steep hoof angles during the first lactation are positively related to survival rates to various ages (Choi & McDaniel, 1993). Some cows could be predisposed to laminitic disease as abnormal keratin production has a hereditary basis (Livesey, 1984).

1.5.5 Nutrition

The composition and quantity of dietary concentrates are some of the major factors implicated within nutritionally induced lameness. High levels of concentrates fed in the diet predispose the animal to develop acidosis which has been directly linked to the development of laminitis (Bazeley & Pinsent, 1984; Bergsten, 1994; Ward, 1993a). Work on horses suggests primary laminitic lesions are the result of endotoxin-induced allergic reactions on the walls of the corium capillaries (Ebeid, 1993). This has led to the hypothesis that rapid fermentation of highly degradable starchy carbohydrates by lactobacilli produces high levels of lactic acid which lowers ruminal pH and kill gram-negative bacteria. These dying bacteria release endotoxins which, together with the high lactate levels entering the bloodstream, induce vasoconstriction and the development of arteriovenous anastomoses leading to laminitis in the hoof (Vermunt & Greenough, 1994).

Livesey & Fleming (1984) found that the incidence of clinical laminitis was significantly higher in animals fed low fibre, high concentrate diets, and that the major effects occur at the transitional period while rumen flora adapt to a new diet. Bazeley & Pinsent (1984) suggest that the rumen is unable to buffer the rise in acidity as effectively during a dietary change onto a high carbohydrate regime. Wells *et al* (1995) provided some epidemiological evidence that frequent "balancing" or changing of the diet was associated with higher levels of clinical lameness, however this finding was confounded with a number of other interrelated factors associated with year round housing systems. Manson & Leaver (1989) placed cows on either a 60:40 or a 40:60 concentrate/forage isoenergetic diet. Animals on the former diet had a significantly increased locomotion score, i.e. had poorer mobility. The incidence of lameness rose and the prevalence was further increased since lame animals remained lame for longer and had softer hoof horn. However Bergsten & Frank (1996b) using a similar concentrate/forage contrast found there were few problems, possibly due to the dietary ration being allocated in small meals throughout the day, which would not lead to wildly fluctuating rumen conditions. The type of fermentable constituent appears to be important: Kelly & Leaver (1990) found that a diet based on barley and soyabean induced a similar increase but higher prevalence of clinical lameness than a isonitrogenous diet based on distillers' grains and sugar beet pulp. Barley has been implicated in the development of laminitis as it is high in histidine. Within the rumen the histidine is converted to histamine which enters the circulation possibly initiating the process of arteriovenous anastomoses formation in the claws (Vermunt & Greenough, 1994). Although histamine is produced by microbial decarboxyllation of histidine in the rumen, it is unclear what physiological level is required to initiate laminitic damage, or even whether any rumen-generated histamine is able to pass the liver without being assimilated or metabolised. Work by Eyre *et al* (1973) demonstrated that infused histamine reduced blood pressure in the femoral artery of young calves. However this affect on blood supply may not be important as Boosman (1980) showed conclusively that high intravenous levels of histamine do not consequently cause laminitic damage in the feet of mature cows. Therefore in conclusion, it is unlikely that the increases in histamine due to dietary factors would be a common cause of laminitis in dairy cattle.

Protein within the concentrate ration is also linked to lameness in both quantity and source. Manson & Leaver (1988 a, b) found that increases in the level of crude protein significantly increased the level of clinical lameness; there were also non significant increases in locomotion score. Excess rumen degradable protein (RDP) can produce ammonia and other toxic degradation substances which affect corium function (Ward, 1993a). However Offer *et al* (1997) found no significant difference in locomotion or other lameness parameters between animals fed contrasting diets containing either high levels of rumen degradable soya bean meal or high levels of rumen undegradable fishmeal. Clark & Rakes (1982) fed a methionine hydroxy analogue in a complete diet mix. Cows fed this analogue had faster growing hooves but their hoofs contained less cysteine (another sulphur containing amino acid) and they were significantly softer, potentially increasing the risk of traumatic claw disorders. High protein levels in spring grass could create or prolong lameness at turnout (Vermunt & Greenough, 1994).

Silage composition is also important: cows fed silage high in dry matter (DM) were less lame than cows fed wetter silage (Ward, 1993a). The DM content could be affecting saliva production and hence be influencing the rumen buffering ability as a defence against acidosis.

Deficiencies in trace elements (TE) are an obvious factor which could be involved in the development of lameness. Poor hoof horn formation due to low TE status will probably have more effect in heifers calving at two years old when tissues are still growing (Bazeley & Pinsent, 1984). Zinc and biotin are the major dietary supplements which have been fed to improve hoof quality (Ward, 1993a) and are widely used supplements in equine diets for this purpose. Some epidemiological studies have shown reductions in lameness diseases using zinc methionine and zinc sulphate, by comparing supplemented and non supplemented farms (Chesterton *et al*, 1989; Dembinski & Wieckowski, 1990; Kellog, 1990). Distl & Schmid (1994) report that a supplement of biotin at levels of 20 mg/cow/day improved claw hardness and conformation and reduced the incidence of interdigital and sole diseases compared to control animals. Recent work has shown that biotin has relatively minor effects on hoof health (Midla *et al*, 1998) and has to be supplemented at high dietary levels for long periods to reduce the level of herd lameness (Fitzgerald *et al*, 1998). Work using goats as the model subject has shown that they have to be severely biotin deficient before any abnormal keratin changes in the hoof are seen (Galbraith *et al*, 1998). It would appear that although biotin is extremely important in some species e.g. pigs, its influence on the hoof health of cattle is minor.

1.5.6 Management

Foot trimming is the most basic care that can be given as a preventative measure against lameness disease (Toussaint-Raven, 1985). Trimmed claws are shorter and have an increased angle which helps reduce the incidence and also the duration of clinical lameness cases (Vermunt & Smart, 1994). Those authors also concluded that dairy cows should be foot-trimmed just after calving to correct overgrowth (Vermunt & Smart, 1994), and cows foot-trimmed regularly are less restless when standing in the parlour, thus improving conditions for the dairyman (Albright, 1993). Faye & Lescourret (1989) found that the incidence of foot disorders was higher in herds where preventative trimming was carried out more than once per year. This could however be due to the fact that herds with an intrinsically high incidence of hoof disorders are trimmed more frequently.

Footbaths are a recommended management routine in that they can reduce the incidence of infectious foot diseases by exposing the feet to a treatment chemical and simultaneously washing the abrasive and contaminating material from the foot (Logue, 1994). The use of formalin and zinc or copper sulphate salts hardens the claw horn, making it more resistant to abrasion and reducing lameness risk (Vermunt & Smart, 1994). However there is now evidence that copper sulphate treatment may actually be harmful to the integrity of the claw horn (Kempson, pers. Comm., 1998).

1.5.7 Stockmanship

The interaction between the stockman and the dairy herd is difficult to measure quantitatively but the deleterious effects of poor stockmanship are all too obvious (Hemsworth *et al*, 1995). An area which seems to have been singled out in the literature is movement of the herd along tracks or through yards. Insensitive herdspersons using physical force and/or dogs force animals at the back to bunch forward, enhancing the risk of lameness (Chesterton *et al*, 1989). The problem is exacerbated as the trailing cows are generally those which are clinically lame and need to be walked at their own pace to prevent further injury and limit pain (Clackson & Ward, 1991). The patience of the stockman is positively linked with a reduced incidence of lameness (Chesterton *et al*, 1989; Clackson & Ward, 1991), perhaps because unhurried cows are less likely to become lame as they are able to anticipate and negotiate problem obstacles such as gateways and damaged portions of the track (Chesterton *et al*, 1989).

The knowledge of the farmer or stockperson is also highly relevant. Mill & Ward (1994) in a survey of farms found that farmers who know more about lameness, are trained in the treatment of lameness or are aware of how many lame cows they have, tend to have fewer lame cows.

1.5.8 Farm tracks

Inadequately maintained, uneven, rough or stony tracks have a direct effect on the incidence of lameness as they cause traumatic injury irrespective of other factors. Indirectly, poor track surfaces also crowd the herd together, slowing it down and inducing impatience in the stockman, enhancing the risk of lameness (Chesterton *et al*, 1989). In a comprehensive survey of farm tracks in England and Wales, Faull & Hughes (1993) concluded that outdoor walking surfaces were generally unsatisfactory. Reduced lameness was evident on farms where outdoor surfaces were satisfactory, i.e. smooth surfaced and well maintained. Conversely, increased incidence was seen where tracks were poorly maintained (Clackson & Ward, 1991). Wet tracks, sharp corners and poorly maintained gateways have been identified as risk factors for lameness (Chesterton *et al*, 1989; Clackson & Ward, 1991). However, despite this, Clarkson *et al* (1993) found no significant association between walking surface and lameness in their study. The quality of the tracks therefore may not be directly involved with the initiation of lameness but may help prolong or exacerbate diseases already present or developing.

1.5.9 Housing

In the UK, due to adverse weather conditions and availability of suitable pasture, dairy cows are housed for about five months of the year. Lameness prevalence is directly associated with the housing period (Thysen, 1987; Clarkson *et al*, 1996; Murray *et al*, 1996), which appears to be one of the most influential factors in epidemiological case control studies. Faye & Lescourret (1989) in an extensive survey on the environment and lameness incidence of French herds show conclusively that lesions rise in response to housing, and although there is a problem in that the simultaneous effect of calving cannot easily be separated, they show that the length of the housing period itself has a large influence on lameness. At worst the effects of different aspects of housing are often additive, the results being severely detrimental for the maintenance of foot health. The length of the housing period is a factor in itself; Toussaint-Raven (1985) concluded that cows recover from laminitic and other forms of lameness diseases on pasture, therefore a reduced time at pasture affects recovery rate. The transmission risk from infectious foot disease is significantly higher during housing due to the close proximity of herdmates and constant presence of slurry (Peterse, 1987).

Flooring type affects the development of lameness, for example hard floors are directly associated with the development of laminitis (Bergsten, 1994). Cattle housing requires a non-permeable, long-wearing, abrasion-resistant surface which offers ease of slurry removal and is cheap; for these reasons concrete is widely used. Cows' feet are not adapted for surfaces with low coefficients of friction such as concrete. The unnatural smoothness of the surface results in slips and falls directly causing traumatic damage to the legs and claws (Metz & Wierenga, 1987; Herlin, 1994). Faull & Hughes (1993) in a comprehensive survey of 37 farms, found that herds housed on smooth concrete had significantly worse lameness rankings. The settling of slurry on concrete surfaces caused by inadequate removal increases the incidence of infectious foot disorders (Wee *et al*, 1989). Sudden introduction to such an unfamiliar surface has been linked to high incidence of laminitic lesions in heifers (Bazeley & Pinsent, 1984, Vermunt & Greenough, 1994). Murphy *et al* (1987) found that the hoof horn of beef cattle on concrete is more susceptible to abrasion than that of animals on straw yards.

Slats are an alternative to solid concrete floors, and offer ease of slurry removal as urine and faeces drain by the action of animals' feet during movement over this surface. The spacing of slatted floors is crucial, as there is a trade-off between ease of locomotion and manure handling (Kirchener & Boxberger, 1987). Slat space does not usually take into account the natural stride length and walking rhythm of the cow. As a result there is unnatural weight bearing often associated with lameness problems (Kirchener & Boxberger, 1987). Many authors have reported a decrease in locomotory activity when cows are moved onto slats (Zeeb, 1987; Wee *et al*, 1989). This decrease in locomotory activity could possibly be the result of the apprehensiveness of cattle moving on slats. The reduction of locomotory activity could decrease the supply of blood to the corium and enhance the risk of laminitis (Vermunt & Greenough, 1994). Compared to solid floors, slats have higher associated incidences of heel erosion but lower incidence of laminitis and sole ulcer (Murphy *et al*, 1987; Greenough & Vermunt, 1991; Herlin, 1994).

Passage ways and walking areas are often constrictive to the through-flow of individuals, and subordinate animals often have to turn quickly to avoid dominant cows, causing shearing and damage to the hoof horn (Greenough & Vermunt, 1991). Dewes (1978) recommended reducing the angles of approach between races and widening walkways to allow ease of movement. Confrontation could be avoided by increased passage width and the provision of 'escape areas' (Wierenga & Peterse, 1987).

Feeding areas often present problems as cows at mangers have been observed to spread their forelegs apart to reach the feed and consequently overload the inner front claws (Toussaint-Raven, 1985). Due to the proximity of other herd animals feeding, agonistic confrontations are often seen at the feed area (Metz & Wierenga, 1987). Fights often occur and presumably animals slip and injure feet and legs during these altercations.

The provision of lying areas in the form of cubicles influences the development of lameness in that badly designed cubicles will not only cause direct injury to the animal but deter the animal from using them. This results in more time spent standing on concrete and exacerbating the incidence of lameness (Metz & Wierenga, 1987). Cermak (1987) reports that 50% of cubicles in the UK are too small, due to the trend for increasing body size of today's selected breeds. Short cubicles and badly placed division bars cause limb damage when lying and rising, leading to lameness (Cermak, 1994). There is a significant positive correlation between short cubicles and the incidence of lameness (Faye & Lescourret 1989; Zrelli *et al*, 1994). Clarkson (1993) suggests that unsatisfactory cubicle design such as short beds and high kerb height are responsible for increasing the incidence of lameness cases. Herlin (1994) using image analysis of locomotion, found that cubicle-housed cows compared to loose and tie-stalled cows did not open the elbow joint as much and had a decreased hock joint flexing angle when standing - a possible result of poor lying position or more exercise in cubicle housing. This could be a further influence on the development of lameness. Furthermore Bergsten & Herlin (1996) contrasted tie stalls and free cubicle housing and found that the levels of subclinical white line lesions and incidence of lameness were higher in cubicles over a 3 year period, perhaps indicating that locomotion on concrete is a very real risk. This evidence for increased lameness risk however must be tempered with the improved welfare of untethered cows which are able to engage in a variety of "normal " behaviours within a free stall environment.

A comparison of the effects of Dutch Comfort and Newton Rigg cubicles on lying time and claw health was conducted by Leonard *et al* (1994). They found that Dutch Comfort cubicles increased the lying time of animals and reduced the deterioration in claw health during the housing period. Due to the effect of cubicle comfort on lying time many authors have stressed the importance of providing a comfortable lying area to prevent lameness (Cermak, 1987; Metz & Wierenga, 1987; Wierenga & Peterse, 1987; Vermunt & Greenough, 1994).

1.5.10 Behavioural influences on the development of lameness in dairy cattle

Studies into the behavioural factors involved in the development of lameness have suffered from the complexities of identifying causes. For example, to dissociate the effects of social and environmental interactions on individual cow activity budgets. The following review does not attempt to rank single factors in order of importance but broadly to categorise associated behaviours from the literature.

Social behaviour and rank

In the bovidae family the most common form of social structure is the 'matriarchal' herd built from the permanent association of older females and their offspring. In domestic cattle, especially under intensive husbandry conditions, such organisation is modified, with the elimination of the maternal bond, rearing in groups of one sex and the same age and reduction of personal space to a few metres (Hafez & Bouissou, 1975). The behaviours which establish a social hierarchy are by far the most important as these dictate the order in which animals budget their activity throughout the day. The dominance hierarchy affects animals' access to resources such as space, food, water, and lying area. This is indicated by the appreciable amounts of time cows spend anticipating the movements of dominant and subordinate herd members (Miller & Wood-Gush, 1991).

Position in the dominance hierarchy is positively correlated with body weight, and as body weight reaches a maximum at eight years of age, heifers and older cows (aged ten years or more) are usually lower in the hierarchy (Reinhardt & Reinhardt, 1975). Kerr & Wood-Gush (1987) found that frequency of social encounters, particularly aggressive encounters decreases with age, this supports the observations of Reinhardt & Reinhardt (1975) that heifers have increased incidence of agonistic interactions. There is a significant rise in agonistic interactions during the housing period (Miller & Wood-Gush, 1991), mainly due to the increased competition for feed and lying areas caused by crowding (Metz & Wierenga, 1987). Dominant cows have priority at the feed sites (Friend & Polan, 1974) and spend more time feeding uninterrupted (Arave & Albright, 1981). Potter & Broom (1990) found that high rank individual cows feed at the ends of the feed barrier which causes an aversion response by low ranking cows to feed. Consequently these cows spend more time standing and less time feeding. Access to drinkers appears unaffected by the dominance hierarchy as dominant animals are displaced as often as subordinates (Miller & Wood-Gush, 1991). As water is always available, access to it is of minor importance, therefore dominant animals may not contest a threat made by a less dominant individual.

Position in the social hierarchy determines how the herd members utilise cubicles. Given equal cow/cubicle ratios and plenty of walking area, dominant cows have fewer resting periods but of longer duration (Friend *et al*, 1977), although at higher stocking densities low ranking animals remain in the cubicles for longer (Metz & Mekking, 1984). An explanation for this is that a subordinate animal would avoid confrontations with higher ranking animals by using the cubicle to increase her effective personal distance (Metz & Wierenga, 1987; Potter & Broom, 1987). Displacement of cows from cubicles is common, either by direct physical contact or threat posture. However, low ranking animals often attempt to displace high ranking individuals from cubicles; in this instance the cubicle area prevents the more dominant animals from turning and retaliating (Wierenga, 1986). Generally low ranking animals are displaced twice as often from the cubicles (Metz & Mekking, 1984; Galindo & Broom, 1993). Cows which are displaced often, i.e. low ranking individuals, spend more time standing out of the cubicles and in one study these animals had a higher incidence of clinical lameness lesions (Galindo & Broom, 1993). A possible alternative explanation is that these animals were already lame and therefore were less able or willing to compete in aggressive disputes leading to an increase in standing.

Cubicle preference may be influenced by the social hierarchy. Friend *et al* (1977) showed that individual cows tend to lie alongside neighbours of similar rank. However, their study group consisted of only 12 animals and it is not clear how social hierarchy would affect cubicle choice in larger herds. Subordinate animals have also been observed to reject a free cubicle if it had previously been occupied by a dominant cow. Friend & Polan (1974) suggest that even with a cow/cubicle ratio of 1:1 the effects of the two above factors result in inefficient use of the lying area. However in stable herds of up to 60 animals where high production ensures that animals are motivated to lie it appears all cubicles can be occupied with few problems (personal observation).

An individual's position in the social order affects the position in the herd that animal takes when moving to and from the milking parlour (Dewes, 1978). Dominant cows 'hold' low ranking cows at the back of the herd during travel to the parlour, consequently once at the back the low rankers are crowded by the stockman so that they may not be able to see immediate obstacles or the ground to ensure firm foot placement, resulting in traumatic limb damage in some instances (Chesterton *et al*, 1989).

Locomotory behaviour

A certain amount of locomotory behaviour is necessary for the cow to perform normal maintenance activities e.g. visiting the feed area (Krohn *et al*, 1992), and to satisfy a motivation to explore their immediate environment - a behaviour known as patrolling (Wood-Gush *et al*, 1983). During movement the sequential pressure on the digital cushion acts as a vascular pump, to provide adequate blood circulation in the foot (Zeeb, 1987; Greenough, 1994). Distances walked daily can influence the risk of lameness. Dewes (1978) found that long distances walked by the animals to and from milking together with wet conditions and abrasive surfaces were strongly associated with an increased incidence of lameness. Kempens & Boxberger (1987) suggest that the greater the walking distance on concrete floors the greater the risk of lameness due to hoof abrasion and traumatic damage to the limbs caused by slipping. Cubicle-housed dairy cows spend around 5% of their daily activity engaged in locomotory behaviour (Zeeb, 1987). Actual distances walked, however, are small compared to distances walked on pasture: ranges between 400 and 2000m have been reported for housed cows (Kempens & Boxberger, 1987; Krohn *et al*, 1992; Phillips & Schofield, 1994). However the prevention of excessive walking on concrete, particularly during oestrus may have beneficial effects on claw health.

Oestrous behaviour

A comprehensive description of heifer and adult cow sexual behaviour is given by Hafez & Bouissou (1975). They define oestrous behaviour as a period of hyperactivity, where oestrous animals indiscriminately approach dominant and subordinate herdmates and solicit mounting, often by chasing. Understandably the frequency of locomotory behaviour and also the incidence of agonistic interactions increase for an oestrous animal (Phillips, 1993) and highly active animals can disrupt the activity budgets of the majority of the herd. The increase in walking, together with the risk of slipping during mounting attempts, must exacerbate the risk of lameness. Mounting attempts often cause panic reactions within the herd, especially in areas where herdmates are crowded together (Metz & Mekking, 1984) resulting in traumatic injuries by increasing stresses on the claw horn of animals attempting to flee. Activity increases gradually for 80 hours before oestrus (Arney *et al*, 1994). Phillips & Schofield (1994) found that cattle housed in straw yards show more profound behavioural changes than animals in cubicles during oestrus in that they show less lying, more standing and more associative behaviour such as sniffing and licking herdmates. However no indication is given as to whether this behaviour disturbed or interrupted lying and feeding bouts of other individuals. Diet and general body reserves could influence the amount of locomotion, as oestrous cows with higher energy intake had a higher locomotion coefficient than lower energy oestrous cows (Arney *et al*, 1994).

Feeding and ruminative behaviour

Cattle are very effective at adapting their ingestive behaviour to meet physiological and environmental changes. Actual feeding or grazing times can be misleading as it is the actual rate of feeding governed by bite size and frequency which is a more accurate evaluation of how much a cow is ingesting (Arave & Albright, 1981). Kempens & Boxberger (1987) found that cows which had a higher frequency of feeding bouts during the housing period had the greatest daily walking distances. Feeding time is known to increase steadily over a four week post partum period. Compared to the gestating animal, feeding time increases relatively by 50% post parturition (Ruckebusch, 1975). This increase in feeding time correspondingly increases standing time and may increase the locomotory behaviour of the animal which are factors associated with increased lameness risk.

Ruminative behaviour has been suggested to reduce the risk of acidosis and hence laminitis. There have been few definitive studies on this, however Singh *et al* (1993a) reported that there is no correlation between rumination time and the incidence of sole lesions.

Lying behaviour

Cattle are typical of most mammalian species, requiring a certain period of recumbency within any day to prevent fatigue (Arave & Albright, 1981), the exact length and frequency of lying periods depending on the animals' immediate environment, social position and output. Indeed Wierenga & Hopster (1990) report that dairy cows show strong reactions to changes in environment which cause a decrease in lying time. When an animal is lying, it reduces the time spent with its hooves contacting a solid surface which in turn may have direct effects upon the development of hoof diseases such as laminitis. Studies have shown that there are strong correlations between the incidence of foot lesions and lying time (Singh *et al*, 1993a; Leonard *et al*, 1994). There is some evidence that cows which lie down for shorter periods are more likely to become lame (Colam-Ainsworth *et al*, , 1989; Ward, 1993b). However once lame a cow will lie down for longer, and more often during daylight hours relative to unafflicted cows (Singh *et al*, 1993c).

Cows have definite preferences for where and when they lie; the majority of the herd lies synchronously and there is a definite circadian pattern associated with lying behaviour as the bulk of lying time occurs between midnight and 6.00a.m. (O'Connell *et al*, 1989; Singh *et al*, 1994). Cows prefer to lie on soft surfaces: when offered access to pasture, deep bedding and cubicles, cows lay more often and for longer on pasture, less on straw and least in cubicles (Krohn *et al*, 1992). Along with surface bedding material the actual amount of lying area is important. Cows prefer straw yards to cubicles because their movement is unhindered during lying and also they are disturbed to a lesser degree by other cows, provided there are few animals in oestrus (Singh *et al*, 1994). The increased space allowance together with the above factors result in longer and more uniform lying times (Krohn & Munksgaard, 1993; Singh *et al*, 1994; Ward, 1993b). Lying time in cubicles is significantly increased by changing the cubicles' design to a more cow-friendly space (Leonard *et al*, 1994) and also increasing the comfort overall either by deepening the bedding material or putting a more deformable material down.

As already noted, the majority of hoof lesions occur following calving and this may be associated with the fact that lying time falls by up to 50% post calving before stabilising and rising after peak yield is reached (Ruckebusch, 1975). Apart from the direct effect of lying, another contributing factor may be that the amount of time spent ruminating is strongly influenced by lying time (O' Connell *et al*, 1989; Hassall *et al*, 1993; Singh *et al*, 1994). Therefore cows which lie for longer, ruminate more and increase saliva flow into the rumen, thus reducing the risk of acidosis in animals on a highly fermentable concentrate diet and possibly reducing the risk of laminitis.

<u>Cubicle associated behaviour</u>

The use of cubicles is widespread, indeed it must be the most widely provided type of artificial lying area for dairy cows. Cubicle size, amount and type of bedding material, spacing and height of partitions all affect lying time (Colam-Ainsworth *et al*, 1989; Phillips & Schofield, 1994; Wierenga & Hopster, 1990). Up to 60% of a cow's time is spent in cubicles and cows have a priority for obtaining and lying within a cubicle: if cubicle numbers are limited, cows reduce their time spent standing in the cubicle to increase lying time (Wierenga & Hopster, 1990). Cows are discriminating: if cubicles present problems in lying or rising or have an uncomfortable bedding material then the animal will either reduce lying time or refuse the cubicle altogether (Metz & Wierenga, 1987; Colam-Ainsworth *et al*, 1989; O'Connell *et al*, 1991). Cubicle refusal has serious implications for increasing the risk of lameness by increasing walking and standing times (Vermunt & Greenough, 1994). The provision of straw yards allows cows to lie for longer without interruption; this is associated with fewer lameness problems in this type of lying area (Phillips & Schofield, 1994; Singh *et al*, 1994).

Effects of overcrowding on behaviour and lameness.

Overcrowding is probably the major factor which affects behavioural risk factors for lameness diseases. If cows are housed with high stocking densities, activity levels are altered and cows are forced to invade the 'personal space' of their immediate herdmates, increasing the underlying incidence of aggression (Chesterton *et al*, 1989; O'Connell *et al*, 1989; Cermak, 1994). Crowding in narrow passageways or by herding to and from yards increases agonistic confrontations as subordinates cannot express submission (Arave & Albright, 1981). Such confrontations result in mechanical damage to the feet especially if the surface is abrasive (Chesterton *et al*, 1989; Metz & Wierenga, 1987; Vermunt & Greenough, 1994). A reduction in idling space does not always result in an increase in aggression: Arave *et al* (1975) reduced space per cow from 9.3 to 2.3 m^2 for a 17 cow group and this resulted in fewer aggressive encounters. However, caution must be exercised in interpretation of these findings, as these cows were initially kept at the higher space allowance for some time before being crowded and it is possible that the initial high level of aggression was a result of establishment of a dominance hierarchy, which once stabilised will reduce the amounts of aggressive interaction during the subsequent crowded treatment. A similar response occurred in group housed pigs (Barnett *et al*, 1992; 1993). Potter & Broom (1987) found that restricting passage entrances meant that cows circulated in one direction leading to fewer head to head confrontations. Reducing the size of the walking areas reduced cows' overall locomotory activity (Arave *et al*, 1975; Metz & Mekking, 1984).

Crowding of animals around the feeding area reduces feeding time (Prescott, 1992), and reducing the number of feed spaces increases aggression and chasing by dominant cows (Potter & Broom, 1990). Crowding generally reduces lying time (Arave & Albright, 1981), frequency (Friend *et al*, 1977), and overall cubicle use (Wierenga & Hopster, 1990). Thus when Leonard *et al* (1994) reduced cubicle numbers to a 2:1 cow/cubicle ratio, lying time was reduced from 7-10 hrs to 5 hrs. The reduction in lying time was correlated with a significantly higher lesion score but lesions found in these animals were less severe than are seen in some herds, suggesting that lying time alone is not the entire explanation. Metz & Wierenga (1987) found that the lying times of the low ranking cows were more severely affected by cubicle overcrowding compared to high ranking cows.

1.6 Conclusions

Lameness is a complex disease that affects a large proportion of the dairy population. The small number of surveys over the past two decades have shown that lameness incidence is increasing. This is a serious concern for the dairy industry and welfare bodies. The majority of lameness cases occur in the claw, and within this area it is diseases specifically affecting the claw horn that are the commonest and most costly. The other type of disease in this area occur as a result of infection, and in contrast to claw horn diseases, are far simpler to prevent.

Disorders of the claw horn occur due to generalised disruption of the keratin producing corium resulting in poor quality horn formation and, if severe, cessation of horn production. This leaves affected claws vulnerable to physical insult and trauma and therefore more prone to lameness. The factors involved in the initial insult causing the damage to the corium and affecting horn production appear to be numerous but can roughly be separated into primary, secondary and internal factors. The literature shows there is considerable overlap and interaction between specific factors in these categories. Primary factors of "claw horn disruption" are the main causes of lameness diseases and include calving, nutrition and traumatic damage due to concrete. Secondary factors are not usually the direct cause of lameness but certainly affect its severity- such things as behaviour, housing design and management. Internal factors are the most speculative covering such things as genetics, conformation and animal age. The most common risk factors identified by many authors in this review are calving and the exposure of the animal to the housing environment. In summary there have been few studies investigating the effect of management or showing conclusively that behaviour has a large impact on lameness development.

1. 7 Background to the thesis

Preventative measures to counter lameness are the desirable option but, due to the complex multifactorial development, the majority of preventative management procedures are based on anecdotal opinion rather than a solid research base. There was therefore considerable scope for a detailed study on the effects of specific factors for the more important lameness diseases relative to calving and housing times. Due to the interactive nature of lameness risk factors, either additive or negative, it is difficult to elucidate the risk to the individual in any given dietary, management or housing system. At calving there are dramatic changes in diet and management as well as adjustment of individual's maintenance activity budget. Furthermore there are wide variations in management within the UK. This study looks at two specific systems that have been implemented using the same initial resources which reflect the divergence in dairy management strategies that will occur in the near future.

In subsequent chapters the results of this study are reported. First the effect of diet and management will be studied as these may be singled out in the literature as two of the most influential factors contributing to the development of lameness. In addition the effects of these factors on the animals' behaviour was observed to determine whether this had a secondary effect upon the development of lameness. To eliminate as many confounding environmental and genetic factors as was possible, the two herds studied were of equal genetic merit and were housed identically. As lameness is very much an individual response it was vital to collect as much information at the individual cow level as possible to provide a detailed model of specific disease development.

2 General methods: Farm description and study techniques

2.1 Introduction

This chapter was written to provide the reader with a complete description of the experimental conditions, animals and techniques used in the majority of this thesis.

The study was conducted at the Acrehead dairy unit, SAC Crichton Royal farm, Dumfries. This unit was established as a systems study facility in 1980 and at present is investigating the effects of high and low dietary energy input systems on production. The system consists of two separate milking herds, of similar genetic potential, housed and managed by the same individual. This allowed a comparison of extensive and intensive pasture and winter feeding management regimes at the animal and farm level (Table 2.1).

Table 2.1 Comparison of both units

	Unit 1 Low input herd	**Unit 2** High input herd
Pasture	Mixed grass clover pasture	Perennial rye grass (PRG)
Silage	Grass Clover	PRG
Approx. concentrate useage (t/cow/year)	0.5	1.9
305 day yield (l):		
Year 1 94/95	5350	6700
Year 2 95/96	5800	8200
Milkings per day	2	2 (year 1) 3 (year 2)

2.2 Animals

2.2.1 Herd composition and breed type

Each unit's herd comprised Holstein Friesians of very similar genetic potential bred to Holstein sires. Cows ranged from 1st to 11th lactation with a mean of 3.5 for the low input unit, unit 1, and 3.7 for the high input unit, unit 2.

Herd composition in terms of parity and calving season within each year of the study is shown in table 2.2. This table includes the animals completing lactation only and not those culled or sold before drying off.

Table 2.2 Parity composition of herds (A=autumn, S=spring)

Year	Parity		1	2	3	4	5	6	7+	total
1994-1995	Unit 1	A	8	4	9	4	4	5	5	
		S	7	10	9	3	3	0	5	73
	Unit 2	A	8	6	8	4	4	4	3	
		S	7	7	9	6	4	3	0	73
1995-1996	Unit 1	A	9	5	2	3	4	2	5	
		S	8	6	3	5	2	2	3	59
	Unit 2	A	10	5	6	6	4	3	2	
		S	8	5	4	4	5	2	1	65

ITEM (index of total economic merit) structure of each unit is shown in Table 2.3. ITEM is calculated from weightings given to yield traits (milk yield, fat, protein) and from traits that are predictors of longevity (angularity, foot angle, udder depth, teat length) and accounts for respective predicted transmitting abilities (Simm *et al*, 1995). An ITEM of 22 or above puts the herd in the top 5% of the UK herd for genetic standards (based on ADC summaries for 1997).

Table 2.3 ITEM structure of each unit

Lactation group	UNIT 1	UNIT 2
1st lactation	32	33
2nd lactation	33	37
3rd lactation	32	28
4th lactation	22	22
5th lactation	17	13
>5th lactation	8	-1
Overall	24	22

Replacement stock was derived on farm and generally heifers enter the first lactation at around 22-30 months of age, with a mean of 25 months.

Cows calved either at grass or in individual straw pens and calves were suckled for one day before weaning and being removed to a separate rearing shed about 1 mile from the Acrehead unit. Here they were fed on milk powder concentrate before being introduced onto a molassed solid mix at 4 weeks of age. Subsequently between 4 -6 weeks of age the heifer calves were returned to the Acrehead unit and raised in group pens and fed a diet of home grown barley, soya concentrate and silage. Turnout weights of 200kg and above were aimed for, and exact turnout dates were typically dependent on grass growth and weather in early spring. Heifers were mated at around 12-16 months of age, using a standard synchronisation programme consisting of prostaglandin injections.

2.2.2 Experimental groups

In the first year of study (1994/95) thirty spring and autumn calving heifers from both units were studied- this group will now be called group I (Table 2.3). In the second year of study (1995/96), the divergence in terms of overall production between the low input herd, unit 1, and the high input herd, unit 2, was increased by placing unit 2 on a three times a day milking regime and increasing the proportion and amount of concentrates in their diet. Within unit 1, the dietary and milking regime remained essentially unchanged. There is a potentially confounding effect of milking frequency on milk yield. The increased milk yields seen in unit 2 were clearly influenced by the additive dietary and milking factors. However it was not possible to milk unit 1 animals 3 times a day due to financial constraints on the farm. This work was conducted in conjunction with another project on this farm, which took priority, necessitating the output of unit 2 to be increased as far as possible. One of the means available to do this was thrice daily milking of the entire herd, in contrast to unit 1.

In 1995/96 another group of thirty five autumn and spring calving heifers were included in the longitudinal study- this group will be called group II (Table 2.4). Surviving animals from group I were followed alongside group II in the second year (95/96).

In both years all first calving animals were placed on trial. Unfortunately due to the management strategy for replacement stock, animals could not be moved between herds to balance calving season differences. However as it was, the animals were reasonably balanced in terms of calving season numbers between units as was practical in this systems study. In the second year all animals moving into their second lactation were placed on trial as these were the animals studied in depth from the first year. The reason for using these animals as opposed to other, older cows was that their history of foot lesions was known.

Table 2.4 Numbers and distribution of in depth study groups

<table>
<tr><td colspan="2">Year 1(94/95) group I</td></tr>
<tr><td>UNIT 1
(Low input herd)
15 heifers (8 autumn, 7 spring)</td><td>UNIT 2
(High input herd)
15 heifers (8 autumn, 7 spring)</td></tr>
<tr><td colspan="2">Year 2 (95/96)</td></tr>
<tr><td colspan="2">Group II</td></tr>
<tr><td>UNIT 1
17 heifers (9 autumn, 8 spring)</td><td>UNIT 2
18 heifers (10 autumn, 8 spring)</td></tr>
<tr><td colspan="2">Group I- animals surviving from year 1 and going into their second lactation in year 2</td></tr>
<tr><td>UNIT 1
11 cows (5 autumn, 6 spring)*</td><td>UNIT 2
10 cows (5 autumn, 5 spring)*</td></tr>
</table>

*In year 2 some of the autumn calvers in group 1 "slipped" into the spring calving group due to unsuccessful servings towards the end of year 1.

2.3 Farm type and situation

The farm covers 82 hectares of floodplain lowland and rises from 0-50 metres on sandy loam/alluvial silt soils. Pasture land is divided equally between each unit, low input clover system, unit 1, has a grass clover mixed sward of perennial rye grass (PRG types: Melinda, Magella), large and medium leaf clovers (types: Menna, Donna, Alice and Milkanova.). The high input system, unit 2, has only PRG. Each unit has a separate slurry containment system so that only slurry particular to that unit is spread on the appropriate pasture. Cows are moved to and from pasture along packed gravel or concrete tracks and most fields have perimeter electric fencing. The pasture for each herd was equally divided across the entire farm area with animals grazing in locations predominantly equidistant from the milking parlour and walking along the same types of track. Although the exposure to the types of walking surfaces was similar for both herds, in the second year Unit 2 animals were walking further on these tracks due to their additional evening milking.

2.4 Housing

2.4.1 Cubicle housing

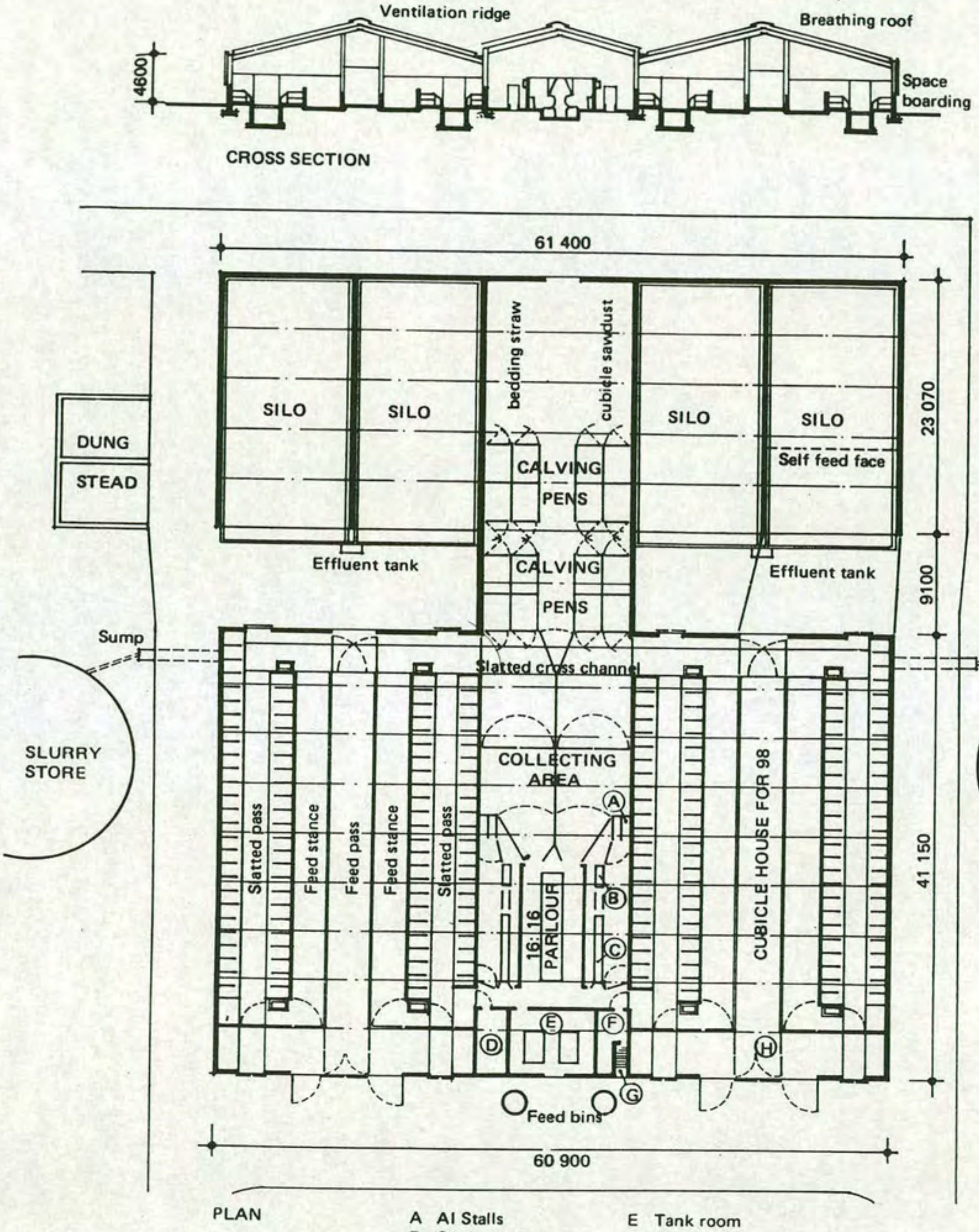
The following section is a brief summary, if further detail is required refer to Leaver & Shepherd (1981). Winter accommodation consisted of cubicle housing, of Newton Rigg type cubicles with a cubicle cow ratio of at least 1:1. Cubicles were 2.1m long and 1.2m wide with a headrail; there was no mat or brisket board, only a bed of sawdust on a smooth concrete surface. Although the cattle at Acrehead are presumably longer and larger than those the cubicles were designed for in the early 1980's, the cows appeared to have few problems lying in them: over the course of the studies there were no instances of cubicle rejection. Cubicles were set in a double row separated by a slatted passage (Fig 2.1). A plan of the buildings and cubicle dimensions are given in Figs 2.3 and 2.4. Although cubicle design and dimensions were identical between rows, the front row had slightly more lunging space as the surrounding wall had been lowered (Fig 2.2). A communal collecting yard and milking parlour separated the two cubicle areas. The feed passage was automatically scraped every 2 hours while the cubicle passage possessed a slatted floor consisting of 15cm slats separated by 4cm spaces. The feed barrier had individual spaces and had locking yolks so that cows could easily be caught and then moved if need be (Fig 2.5).

Individual calving accommodation was situated at the rear of the building and consisted of 13 straw pens of $20m^2$ each.

Fig 2.1 Cubicles and slatted passage

Fig 2.2 Modified cubicle with front wall removed

Fig 2.3 Diagram of the cubicle house



A AI Stalls
B Cattle crush
C Footbath and race
D Compressor room
E Tank room
F Store
G Stairs to gallery
H Water storage above

Fig 2.4 Dimensions and design of acrehead cubicles (from Leaver & Shepherd, 1981)

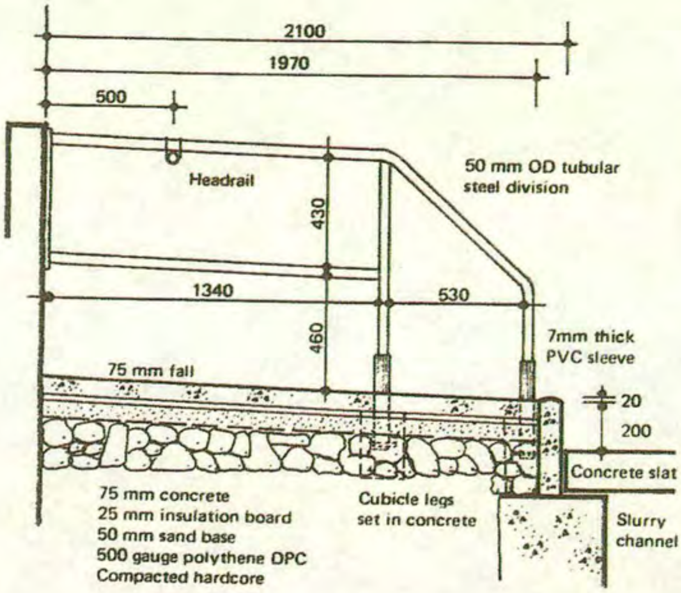
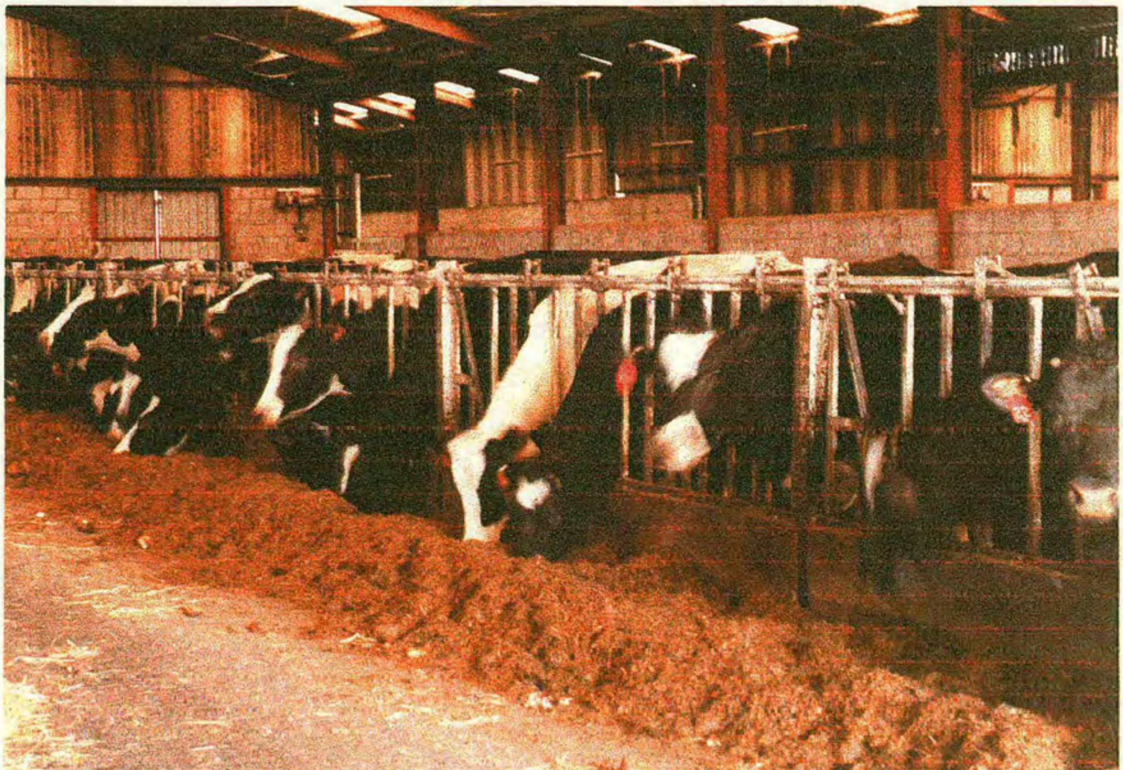


Fig 2.5 The feed barrier and feed passage in use



2.4.2 Milking parlour

All animals were milked in a Fullwood herringbone 20X20 low level jar parlour using standard hygiene practices. Concentrate feed was dispensed into the parlour feed mangers using a Fullwood semi-automatic feeder. Feed units were checked and calibrated monthly.

2.5 Management

2.5.1 Housing and turnout times

Lactating cows were housed from mid September to early April depending on weather. In both years mid September was a transitional time, with cows being kept inside at night and allowed back to pasture in the day. Thus introduction to housing occurred gradually over a period of days. Unit 2 was housed completely by the end of September, but unit 1 cows were allowed a 3 hour period of extended grazing every morning between 8.00 and 11.00am until early December.

2.5.2 Milking regime

In year 1 (94/95) both unit 1 and unit 2 were milked twice daily at 5.00am and at 2.00pm, each milking took approximately 2 hours. Dairy staff were fairly consistent in that one person milked for 10 days who was then relieved for 2 days by a relief dairyman. Milking was simultaneous for both units, each having a side of the parlour so that cows were milked in batches of 10 for each unit.

In the second and third year of the longitudinal study, management was changed in that the high input herd, unit 2, was milked thrice daily (groups I & II). Milking times changed thus:-

Morning milking (both units) started at 4.30am, units milked consecutively; this took between. 1-1.5 hours for each unit, unit 1 first.

Afternoon milking (both units) stated at 1.00pm, situation reversed as unit 2 is milked first.

Evening milking (unit 2) 9.00pm, lasting approx. 1 hour.

Cows were prevented from lying in the cubicles by closing off the cubicle passage, for at least 20 minutes post milking to reduce the risk of mastitis from open teat ends.

2.5.3 General management

During the housing period cubicles were bedded with fresh, dry sawdust twice weekly and raked daily to remove any soiled bedding.

Cows not on in-depth trial were routinely foot trimmed prior to the housing period, and again as they moved onto pasture by a professional foot trimmer. Each herd was trimmed by the same individual or individuals, at the same time. Cows on the in- depth trial had their feet trimmed by the experimenter prior to entering housing; further trimming following subsequent examinations was minimal unless there was a clinical disorder requiring remedial treatment. Lesion scoring and measurement of behavioural variables were only conducted on the in depth group animals. Milking cows were also run through a formalin footbath (conc. 5%) fortnightly.

Herd records on health, fertility and production were maintained using a combination of Farmplan and DAISY packages, thus a detailed history of any animal could be retrieved from these databases. This was especially useful with regard to the clinical lameness study of both units.

2.5.4 Husbandry

One designated full time herdsman and one relief milker was responsible for all cattle.

2.6 Diet

Details of the individual ration estimated from group intakes over the housing period are provided here: details of the proximate analysis of the dietary constituents are provided in the appendix. Also included in the appendix are estimates of the composition of the daily ration available from monthly averages based on the group intakes for each unit.

Yearling heifers

Yearling heifers in both units were initially fed silage at a level of 35kg/head/day plus 1 kg maize gluten per head. Due to differences in silage quality, the levels of maize gluten in the diet were adjusted independently in the two units in order to achieve intended growth rates.

2.6.1 Unit 1 year 1

Silage formed the basis of unit 1's diet. Cows were fed silage (40kg/head/day), grainbeet (10/kg/head/day), fishmeal (0.7 kg/head/day) and maize gluten (4.2 kg/head/day). Parlour concentrate was fed at a rate of 1 kg day.

2.6.2 Unit 1 year 2

In year 2 silage reserves were depleted to a greater extent in the early winter period than they were in year 1. From December onwards a mixture of grainbeet and straw was supplemented to the silage ration (Table 2.5).

Table. 2.5 Winter diet unit 1.

Diet (kg/head/day)	Oct. 95	Nov. 95	Dec. 95	Jan. 96	Feb. 96	Mar. 96
Silage	28.25	25.0	25.0	25	27	14.4
Grainbeet			8.9	6.8	8.7	5.4
Straw			ad lib	ad lib	ad lib	ad lib
Number of straw bales fed			144	246	298	353

The amount of straw is estimated on the amount of bales fed however there was considerable variation between bale weight but a conservative estimate would be that animals were getting at least 3-5 kg/head daily. The amount of bales fed however increased monthly from December until turnout (table 2.5).

Fresh milkers (i.e. animals in early lactation) received 2kg concentrates/day whilst stale milkers (i.e. animals in late lactation) received 0.5kg/day.

2.6.3 Unit 2 year 1

While housed the animals received silage (40 kg/day), Grainbeet (15 kg/day), blended concentrate (4 kg/day) plus parlour concentrate at 2.5kg.

2.6.4 Unit 2 year 2

The winter diet for milking animals was based on grass silage (35 kg/head/day), grainbeet (10 kg/head/day) and a blended concentrate (4 kg/head/day). Fresh milkers received 3kg parlour concentrate whilst stale milkers received 1.5 kg.

Mineral supplementation.

Both units received mineral supplements, this was a standard commercial compound, blended into the mixed ration at 20kg / tonne.

The Appendix provides predicted ration tables for equivalent milk yields for each herd in each year. It can be seen that the estimated ration given to unit 2 in each year was similar but not identical to the amounts in the predicted ration (Tables A.8 & A.9). These differences may be due to the inaccuracies associated with the estimation of individual intakes from group intakes and also the rationing programme assuming different weight loss patterns to the real situation. The input and outputs of unit 2 compared to other recorded farms in Scotland (Anon, 1995;1996) differed in that they produced more saleable milk and were fed more concentrates to sustain this increased production, however the concentrate use per litre of milk produced was similar (Table A.10).

In contrast the actual output in relation to predicted inputs suggests that unit 1 cows were underfed, especially in year 2 (Tables A.6 & A.7). Animals were producing less saleable milk but were also fed markedly less concentrates per cow compared to unit 2 and other Scottish farms (Table A.10). The main problem is that the value of the extended grazing period to this system cannot easily be estimated. This system has its benefits in that it maximises its output from forage resulting in a greater margin over purchased feeds as indicated by the concentrate use per litre of milk produced (Table A.10).

2.6.5 Production measures

All animals were weighed and condition scored once 2 months pre-calving then at fortnightly intervals post-calving, in a conventional crush resting upon a load cell weigher. Wherever possible both condition score and weights were recorded by the same individual. Records of milk yield, fat and protein composition were taken monthly by an independent milk recorder. Initial postcalving mean liveweights and condition score for each lactation are given in the tables 2.6 and 2.7 below.

Table 2.6 Postcalving liveweight by parity over the study period

	Parity	1	2	3	4	5	6	7+	overall means
1994-1995	Unit 1	454	534	574	611	663	679	624	571
	Unit 2	470	516	594	628	605	671	597	568
1995-1996	Unit 1	518	502	556	632	651	628	644	578
	Unit 2	535	597	611	654	652	591	668	608

Table 2.7 Postcalving mean condition score by parity over the study period

	Parity	1	2	3	4	5	6	7+	overall means
1994-	Unit 1	2.60	2.06	2.39	2.93	3.18	3.5	3.34	2.74
1995	Unit 2	2.65	2.37	2.53	2.68	3.37	3.25	3.0	2.75
1995-	Unit 1	2.75	2.25	2.19	2.78	3.0	3.12	3.17	2.67
1996	Unit 2	2.96	2.44	2.70	2.57	2.80	2.6	2.92	2.70

Experimental procedures

2.7 Behavioural observation

2.7.1 Activity

Accurate records of 24 hour general activity patterns were obtained using scan samples. A scan is a record of behaviour (or behaviours) of all members of a group taken at the same moment or at approximately the same time. This method of sampling allowed large numbers of subjects to be observed, and the behaviour of each individual recorded at uniform intervals (Noldus Info.Tech., 1994). The behaviour record of the individual rather than the behaviour record of the group was important as the records of hoof lesions were obtained for each cow, therefore the effect of behavioural correlates are given increased scope at the individual level. Depending on the size of the group under observation either 10 or 15 minute scans were used. A reliability analysis comparing the two sampling techniques on the behaviour showed no significant difference between scan times ($p>0.05$). Two replicates of 24 hours were made over a five day period and observation sessions were conducted in four hour blocks.

Data was collected on an observational data package- Observer, version 3.0 (Noldus Information Technology) using a hand held computer, model- LZ64 PSION organiser II. This package allowed conversion of the summarised 24 activity record to any of the conventional analysis packages.

Animals were identified by means of coloured plastic collars and painted numbers on their flanks using exterior emulsion paint. There was already a nightime lighting system operating in the cubicle house that the cows were very accustomed to, but in addition four halogen spotlights were installed to provide supplementary light for observation. Cows were observed from the central feed passage, and both units were scanned in each watch by the observer walking to and from each feed passage. Some watches were conducted on pasture, field binoculars were used during daylight but at night a torch was used to observe behaviour. The torch was covered in red cellophane, so that the light caused minimum disturbance. In fact both in this study and in others at this farm, the cows were remarkably indifferent (as opposed to youngstock) and showed little response to the observer when approached e.g. by rising from the lying position.

2.7.2 Activity Classes

Behaviour was defined into mutually exclusive categories (Table 2.8) and had modifiers depending on the location of their expression.

Table 2.8 Description of the behavioural categories

CODE	SHORT VERSION	DESCRIPTION
W	**Walking**	Cow walking around passages
STIN	**Standing inactive**	Cow standing inactive in feed or cubicle passages not engaged in any interactive or appetitive behaviour
STIC	**Standing inactive in the cubicle**	Cow standing inactive as above with all four feet in the cubicle
STINC	**Standing inactive half in cubicle**	Cow standing inactive but with only fore feet in the cubicle
STRM	**Stand ruminate**	Cow ruminating in either the feed or cubicle passage
STRH	**Stand ruminate in the cubicle**	Cow ruminating with all four feet in the cubicle
STRMC	**Stand ruminating half in cubicle**	Cow ruminating with just front feet in cubicle
STFE	**Stand feed**	Cow positioned with head through feed barrier chewing or nosing food
STDR	**Stand drinking**	Cow at water trough actively drinking
STMS	**Standing misc**	Cow standing in feed or cubicle passage grooming, rubbing against objects or engaged in oestrous behaviour
STMC	**Standing misc. in cubicle**	Cow standing with all four feet in the cubicle engaged in grooming, rubbing or oestrous activity
STMH	**Stand Misc. half in cubicle**	Cow standing engaged in misc. behaviours as above but with only front feet in the cubicle
LI	**Lying inactive**	Cow lying motionless in cubicle not engaged in any interactive or ruminative behaviour
LIRM	**Lying ruminating**	Cow lying in cubicle actively ruminating
LIMS	**Lying miscellaneous**	Cow lying in cubicle engaged in grooming, rubbing or any other behaviour not defined by the above lying categories

2.7.3 Dates for observation

Initial observations on Group I, Year 1 were conducted post-calving and were timetabled (Table 2.9). Year 2 observations are timetabled in Table 2.10. The dates were set at roughly fortnightly mostly over weekends. In order to investigate the changes in behaviour over the housing period, a resolution interval of 2 weeks was decided upon. This was a compromise between the amount of detail required and what was logistically possible.

Table 2.9 Dates of observations year 1

	Start date for 5 day watch
Watch 1	16/12/94
Watch 2	30/12/94
Watch 3	13/1/95
Watch 4	27/1/95
Watch 5	10/2/95
Watch 6	aborted
Watch 7	9/3/95
Watch 8	24/3/95
Watch 9	7/4/95

Table 2.10 Dates of observations year 2 groups I & II

Watch 1 unit 1 autumn calving group II at grass	10/9/95
Watch 1 unit 2 autumn calving group II first housed	15/9/95
Watch 2	2/10/95
Watch 3	21/10/95
Watch 4	4/11/95
Watch 5 (spring calving heifers first housed)	30/11/95
Watch 6	15/12/95
Watch 7	13/1/96
Watch 8	28/1/96
Watch 9	10/2/96
Watch 10	24/2/96
Watch 11	8/3/96
Watch 12	23/3/96
Watch 13 Last watch before turnout	5/4/96
Watch 14 UNIT 1 only at grass	25/5/96
Watch 15 Both units at grass	14/7/96

2.8 Hoof examinations

2.8.1 Hoof examination procedure

Animals were handled using a Wopa portable foot crush. At a routine examination each foot was lifted in turn, patted with clean sawdust on the sole and brushed to remove any packed sawdust or slurry. In this manner the foot was left in a clean, dry state prior to examination.

Firstly, the area between the claws was checked for any signs of infectious diseases such as interdigital dermatitis and foul by running a finger through the interdigital space- 'finger test'. Interdigital dermatitis is an inflammation of the interdigital epidermis caused by bacterial infection. If signs of any of the above diseases were found they were scored on the scale below (Table 2.11). The presence of any interdigital growths was also noted together with a rough estimation of their size. An interdigital growth or Tyloma is a proliferative reaction of the interdigital skin or subcutaneous tissue to form a firm mass.

Table 2.11 Scoring system for interdigital and digital lesions

Score	Description
1	Some slight unevenness and skin feels rough to finger. (animal may show discomfort at finger test)
2	Obvious small erosions. "Sweet" smell of infection (discomfort shown to finger test)
3	Lesions deeper and weeping. slight swelling and puffiness to skin (definite discomfort)
4	Severe lesions, exudation clearly visible and moderate swelling. Animal may be clinically lame, locomotion score 3 or more
5	Foul. Interdigital space severely swollen, deep erosion actively infected with visible exudation. Animal is definitely lame
6	Severe foul infection. Swelling claw involving pastern

(Digital dermatitis scored as above but the site of infection is on or within the skin against the heel horn)

Claws were then pared to reveal the clean sole horn. Any lesions found including haemorrhages of the sole, underrunning, sole ulcers and heel erosion were scored using the subjective scoring systems below (Tables 2.12, 2.13, 2.14). Sole ulcers and exposure of the corium (e.g. as in a penetration) are obviously far more painful and take considerable time for the cow to recover, therefore the score was extended to account for these lesions.

Table 2.12 Scoring system for solar haemorrhages and ulcers

Visual appearance of lesion	Severity Score
Some red or yellow in horn	1
Clear firm red	2
Deep confluent red	3
Port colouration	4
Red raw	5
Sole ulcer: corium exposed or penetration	6
Severe sole ulcer or septic penetration	7
Infected sole ulcer or severe septic penetration	8

Table 2.13 Underrunning score, classified on depth

Score	Depth definition
1	1mm
2	2mm
3	3mm

Heel erosion was scored on the extent and depth of lesions across the heel area.

Table 2.14 Heel erosion score

Score	Definition (amount of heel affected)
1	1/3 + shallow fissures
2	1/3-1/2+ moderate fissures
3	1/2 + deep fissures

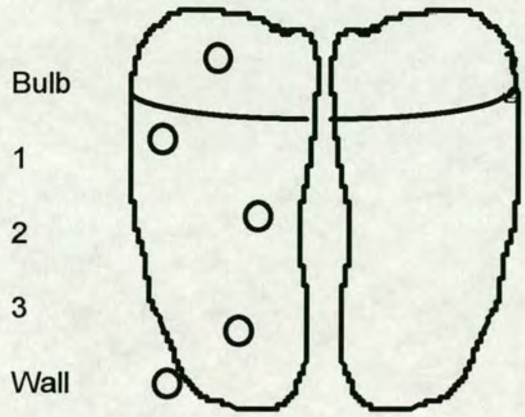
Each lesion was drawn in permanent marker onto the foot to clarify its location and extent. The identified lesions were then copied onto a hoofmap diagram upon which the claw is divided into 6 areas defined by the International Conference of Disorders of the Ruminant Digit (1990) first described by Greenough & Vermunt (1991) (see appendix). To provide a point of reference in terms of drawing the lesions on the hoof map, the anterior margin of the heel was drawn onto the sole using the abaxial/axial groove and termination of the white line as a guideline. The claws were then photographed so that they could be digitally scanned using. a P.C image analysis package- 'Optimas' (®. BIOSCAN).

2.8.2 Other hoof measures

Hardness measurements

A relative measure of hoof horn hardness (in Shore-A-units) was obtained with a shore-a-metre as described by Manson (1986). This is a hand held device which gives a relative measure of the resilience of a substance on a scale of 0-100: a reading of 1 indicates the horn is not very resilient whereas a reading of 100 shows the substance is completely resilient to the pin probe. Measurements were taken 3 times in each of 5 locations in the outer hind claw of the right hind foot of each animal (Fig 2.6).

Fig 2.6 Positions of the hardness measures



Hoof angle and length

Hoof angle was measured on both claws of the right hind foot using a protractor. The length of both claws was measured using plumbing callipers, from the start of the hairline of the hoof to the tip of the toe.

Growth and Wear

To measure the replacement growth and rate of removal of hoof wall due to abrasion during locomotion, small marks were burnt with a soldering iron at regular distances down the wall of the outer hind right claw. Using callipers the distance travelled by each mark from the hairline (coronet) and the distance moved towards the toe could be measured thus growth and wear values could be calculated. By having 2 or more marks on the claw meant that an average growth and wear value could be calculated from these additional marks.

2.8.3 Image analysis and hoof lesion mapping

This method was first described by Leach (1996) and uses a P.C image analysis package- 'Optimas' (®. BIOSCAN).

Image analysis allowed location and extent of lesions to be quantified in terms of:-

i) area coverage for area lesions.

ii) length in terms of white line lesions

Each hoof photograph was digitally scanned on a flatbed scanner to produce a monochrome digitised image. To calibrate the scale of the image, two adhesive paper circles of known diameter were placed on the sole area during the hoof examination and photography stage. Once the circumference of these circles was traced from the digitised image, the package could calculate the relative scale of the digitised image. To determine the area of each claw, the entire perimeter of the each claw was traced extending downwards from the anterior margin of the heel. After the computer had calculated and stored the area of the claw in memory, cursor tracings were made of each individual lesion to measure their length. The location of each lesion was also accurately determined by transposing a hoof zone map from the computer's memory onto the current digitised image. Thus for each claw a detailed summary of lesion type, area/length, severity and location was constructed. All hoof data was saved in ASCII format with separate files being constructed relating to each individual trial animal per hoof examination.

2.8.4 Time of the examination

All feet of in depth trial animals were examined at specific intervals in relation to the housing and calving period (Table 2.15), during both year 1 and 2.

Table 2.15 Hoof examination times for all animals

Examination	Autumn calving animals (both groups)	Spring calving animals (both groups)
1	At grass, two months before housing	At grass, two months before housing
2	Immediately before calving (September)	Before housing (November)
3	Immediately after calving (all housed)	Before calving (Late January)
4	2-3 months post-calving (December)	Immediately after calving (February)
5	5 months post-calving (May)	6 months post housing (June)

2.9 Locomotion score

To enable comparison between the general mobility of the two groups (units 1 & 2) and particular cases of the in depth group studies of the 1st lactation cows, a longitudinal study of the whole herd was conducted. The entire herd (wherever possible) was locomotion scored weekly. A locomotion score is a score of an animals' mobility and can be used to identify animals that are clinically lame. The scoring system was first defined by Manson (1986) (Table 2.16).

Table 2.16 Locomotion scoring system- definitions

Score	
1	Sound gait, walks freely with no unevenness or tenderness. tracking* 75% plus
1.5	Maybe less than 75% tracking. Slight abduction/adduction with no unevenness or tenderness
2	Walks short (tracking 75% or lower). Abduction/adduction present. May have uneven gait or appear tender, possibly arching back and downward extension of head
2.5	Less than 75% of tracking. Abduction/adduction present. Uneven gait and tenderness
3	Slight lameness not affecting normal behaviour
3.5	Lameness obvious, not affecting normal behaviour but difficulty in turning demonstrated
4	Obvious lameness, difficulty turning, affecting normal behaviour
4.5	Lameness affecting normal behaviour pattern considerably. Unwilling to rise
5	Severe lameness, difficulty rising. May not put any weight on most affected foot

* Tracking means the cow is not taking a full, functional stride length but shortening the distance the claw travels forward.

Animals were scored as they left the milking parlour to remove any gait effects of a full udder. The cows walked down a slurry free 6 metre long solid, floored concrete passage and could be easily scored as they went past the observer. Scoring was conducted by the same observer in both years.

2.9 Statistical analysis

A combination of parametric, non-parametric and multivariate techniques was used in this study. Further details of the various tests are provided in the following chapters where appropriate.

3 Clinical case study of lameness at Acrehead: relationship between diet, locomotion score and prevalence of lameness

3.1 Introduction

Lameness is now considered to be a major problem, both in terms of welfare and economic losses in the UK. In a recent report DAISY (dairy information system), analysed data from 50 herds over 3 seasons, showed there were 24 cases of lameness per 100 cows, and lameness was directly responsible for 5.6% of all culls (Kossaibati & Esslemont, 1995). Other estimates of incidence for UK dairy herds range from 25% (Collick et al, 1989) to 54 % (Clarkson *et al*, 1993).

Most of the experimental work in this thesis concerned in-depth lesion, lameness and behavioural observations on selected groups of animals from each herd as a whole. To place the incidence and extent of lameness in context of the farm as a whole, a study of clinical lameness was conducted in parallel with the in-depth hoof examination experiments (which are described in chapters 5 and 6). The study aimed firstly to establish a baseline estimate of lameness on farm, secondly to assess the incidence, extent and type of clinical lameness, and finally, to improve the definition of the risk factors and, if possible, the causes.

To obtain an accurate assessment of the incidence and prevalence of lameness the mobility of each animal was examined on a weekly basis using a proven locomotion score system (Manson & Leaver, 1988a, b). Lame animals were then examined to assess the disease objectively, by recording the type of lesion or condition, its severity and extent.

At Acrehead there was an opportunity to study the pattern of lameness disease within two system study herds, where the effects of housing and genetics were kept constant. The herds however had radically different dietary and management regimes. The following questions were addressed.

- Are there management influences which affect lameness as expressed through a locomotion score?
- Is locomotion score correlated with parameters of production such as liveweight and condition score?
- Are there differences in the incidences and distribution of the various diseases causing lameness between systems?

3.2 Methods

3.2.1 Animals and housing

Every animal in both herds was used in this study; at its onset, unit 1 comprised 32 autumn calving animals and 35 spring calving animals; unit 2 comprised 36 autumn calving animals and 33 spring calving animals. The animals were Holstein Friesian with a lactation range of 1 to 9 (mean lactation 3.3). Further details on housing situation, herd composition, management and diets can be found in chapter 2.

3.2.2 Locomotion scoring

The locomotion scoring technique is described in section 2.9. Locomotion scoring on a weekly basis was implemented on 29th August 1995, when the animals were still at pasture and continued throughout the housing period until July 16th 1996 by this author. Subsequent scoring and lameness investigation were continued by a different observer until March 1998. This chapter utilised findings collected over 1 year from August 1995 to August 1996. Animals were housed for slightly different periods in unit 1 and unit 2; the dates are given below.

Unit 1	Housing	Unit 2
2nd October, 1995	Autumn calvers housed	29th September, 1995
5th December, 1995	Spring calvers / dry cows housed	5th December, 1995
16th April, 1996	Turnout	4th May, 1996

Animals which were lactating whilst at pasture were scored after the afternoon milking as they walked along a 15m concrete passage back to pasture (see housing diagram section 2.4.1). For those pregnant heifers and dry cows that were kept in a separate group at pasture, and so were not moved to the parlour for milking, a different scoring procedure was implemented. The procedure was as follows: the observer walked directly towards the head of the animal, making no arm movements or noises, until an avoidance was elicited, then the animal was scored as it walked away. It became increasingly difficult to detect lame animals at grass but not impossible. These dry cows and heifers were grazing on fairly short pasture and silage aftermaths at the end of August when the ground, which was well drained, was particularly firm. This ground would obviously be softer than concrete but not unduly so, and previous observations provided evidence that severely lame animals had been identified. Following housing these cattle were scored in a similar manner to the lactating cows as they walked down the feed passage. The first recording when initially housed showed that no dry animal coming off pasture was lame.

3.2.3 Clinical lameness examination

Animals scoring 3 or more on the locomotion score system were examined routinely within a week of the observation. On average, cows were examined 2 days post scoring. Any lesions or diseases of the claw or interdigital area were identified and quantified using the scoring systems described in section 2.8.1. Drawings were made of the lesion locations using the description sheet (see appendix). Neither photographs for image analysis nor measurements of hardness, claw length or angle were taken.

If the stockman observed lameness between the observation periods or in a previously sound animal or noticed an animal lifting a leg in the parlour suggesting a problem, the animal in question was examined as soon as possible after this (usually within a day) and treated if deemed necessary. Treatment of lame animals were performed either by the author or a regular veterinary surgeon. On many occasions, cattle were treated by these two people alongside each other.

For this study, new cases of lameness were defined if the animal had locomotion scored 2.5 or below for a minimum time of 42 days. This is in agreement with a later definition by Greenough & Weaver (1997) where a new case of lameness was defined if there had previously been a "sign free" period of 28 (or more) days.

3.2.4 Treatment of lame cows

For this investigation, two levels of study were involved. The first level consisted of animals on in-depth trial (Chapters 2,4,5,6) including a number of groups selected from the herd as a whole. These animals were part of a continuous study, their feet being examined routinely without lameness being detected. All other animals, termed herd animals below, were those not on in-depth trial and were only examined if identified as lame individuals.

Treatment of herd animals

Whenever possible lame animals had all four feet raised, examined and trimmed to Dutch standards which ensured as even a distribution of weight across the claw and as near to an optimum hoof angle of 45° as possible (Toussaint Raven, 1985). In these cases the foot or claw identified as the seat of the lameness was treated last. However in some cases either to reduce the trauma of handling or where the animal had been previously trimmed and further treatment was necessary, only the lame foot was examined. At this examination, all lesions of the claw and interdigital area were defined and recorded on a hoof map recording sheet (see appendix). If the damage was severe, and subsequent remedial trimming led to exposure of sensitive areas which were judged likely to be inadequately relieved by corrective trimming then an orthopaedic shoe was fitted (®Giltspur Cowslips). The shoe is made of a durable plastic resin and was glued in place using an epoxy adhesive. This device adds depth to the unaffected claw, raising the affected claw away from the ground and allowing pressure to be relieved, save for a small area on the toe (McGovern, pers comm, 1997). Any infectious lameness causing diseases such as digital dermatitis and foul-in-the-foot were first treated with a topical aerosol spray -

'®Terramycin' (Pfizer LTD). In cases of foul, the animal was then injected with an antibiotic such as '®Engemycin' (Intervet U.K LTD) which had a relatively short milk withdrawal period.

In some cases where the cow was severely lame (scoring 4-5) and had a severe lesion which would take some time to respond to treatment, the cow was first treated then removed to a separate straw bedded pen close to the milking parlour. Once there, the afflicted animal was allowed to recuperate until she was judged fit to be released back into the cubicle house with the rest of the herd. If there were animals in straw pens recuperating at the time of locomotion scoring, these animals were locomotion scored as they were moved across an empty collecting yard after all the other animals had been milked. If further treatment was deemed necessary they were examined at the same time as any cubicle housed lame animals.

Individual animals on in-depth trial

As part of a more detailed study of the development of lesions associated with each treatment, selected groups of animals (27 unit 1 animals and 28 unit 2 animals) had their feet regularly examined for all types of claw, interdigital and digital lesions (Chapters 5 & 6).

Any individual in this study group that showed clinical lameness signs was examined and trimmed (as little as possible, since this might influence other readings), firstly to identify and secondly to alleviate the source of the lameness problem.

3.2.5 Liveweight and condition score measures

For information on the distribution of liveweights and condition scores and collection of this data refer to chapter 2 section 2.6.5.

3.2.6 Statistical analysis

Any study comparing two groups of animals over a single study period raises the problem of replication. However due to the availability of resources and time scale it was not feasible to replicate this type of system study on another farm (or farms). Furthermore weekly locomotion scoring was implemented in the year following this study. A preliminary analysis shows similar pattern of locomotion scores between units and type of animals.

To compare treatment effects with reference to housing and calving a mean locomotion score over a specified period of time was calculated. Although a set of locomotion scores is not a series of continuous variables and therefore would probably not be normally distributed, by calculating an individual animal's mean score over a number of weeks, a set of continuous variables is created upon which parametric tests can be applied if the residuals of this data were normally distributed. The residuals plotted in these data sets revealed that the variables were slightly skewed towards a higher locomotion score. However under advice from the statistical department (Hunter & Nevinson, pers com. 1998) the effects of this distribution would be extremely minor due to the number of animals involved therefore further transformation prior to analysis was unnecessary. Other tests used were non-parametric.

To compare locomotion scores between early and late calving or housing periods, a Wilcoxon signed-rank test was performed on the difference between specific time periods post calving and housing and the locomotion scores pre housing or calving. This test compares the sum of ranks in a random sample of a symmetric population against a null hypothesis value. In this case the difference between a postcalving and a precalving average is compared with a median of zero. Mean locomotion score over specified periods of time were analysed using GLM ANOVA with treatment (unit 1 or 2), calving season and parity (heifer or cow) and the interactions between them as factors. A t-test was used to compare the mean locomotion score between treatments or calving season at specific time periods in relation to calving and housing. The relationship between liveweight and locomotion score was analysed using Spearman rank correlations. Incidences and distribution of various lameness diseases between dietary treatments were analysed using the χ^2 test statistic.

3.3 Results

3.3.1 Management influences on locomotion score

Effect of housing on locomotion score

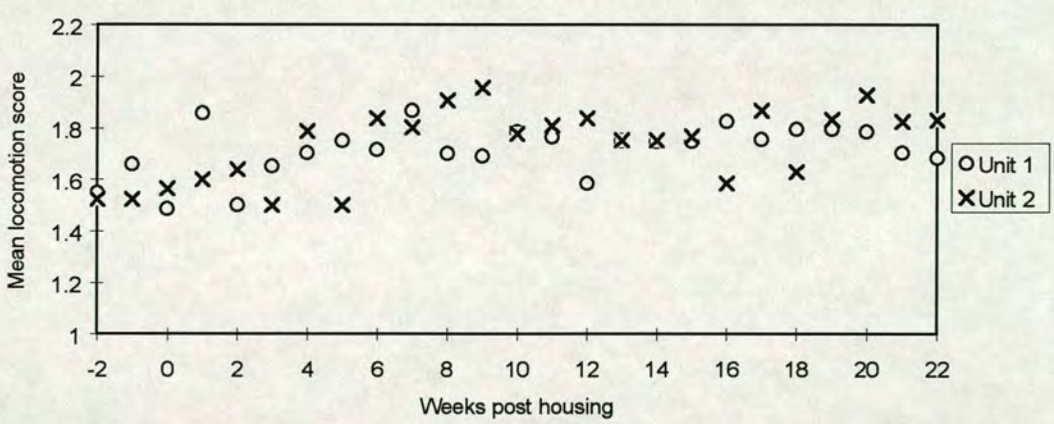
To enable comparison across all treatments, calving season and parity only the 2 weeks before housing and the initial 22 weeks of housing were analysed by GLM ANOVA in this study. There was a highly significant effect of parity as heifers had significantly lower locomotion scores (1.58 ±0.03, mean ±sem) compared to older animals (1.87±0.03, mean ±sem; p<0.01). The interaction of treatment, calving season and parity was not significant (p>0.05), although the highest locomotion scores were the autumn calving groups on both treatments (Table 3.1).

Table 3.1 Comparison of mean weekly locomotion score between treatments over the period 2 weeks pre to 22 weeks post housing

group	Mean locomotion score	S.E.M
Unit 1 autumn calving heifers	1.67	0.12
Unit 1 spring calving heifers	1.52	0.01
Unit 1 autumn calving cows	1.87	0.09
Unit 1 spring calving cows	1.83	0.06
Unit 2 autumn calving heifers	1.57	0.03
Unit 2 spring calving heifers	1.61	0.09
Unit 2 autumn calving cows	2.01	0.06
Unit 2 spring calving cows	1.80	0.06

Mean locomotion scores for each group were plotted over time (Fig 3.1).

Fig 3.1 Mean locomotion scores for the two treatments over the housing period



Locomotion scores during housing were analysed with respect to a locomotion score obtained for all animals in the 2 weeks pre housing. A mean of the 2 week precalving locomotion scores was taken, then the difference between this value and means of two other two week periods was tested by Wilcoxon test, mid housing (weeks 9 - 11) and late housing (weeks 20 - 22). There was a significant increase in locomotion score from the pre housing score to the periods 9-11 and 20-22 weeks post housing ($N=120$; $p<0.001$) (Wilcoxon statistic = 4739 and 4314 respectively). The Wilcoxon statistic corresponds to the smaller of either R, the rank sum of the minority sign (i.e positive or negative) or R', which is equal to $n_2(N+1)-R$ (where n_2 is the number of observations for the minority sign and N is the total sample size) (Anon, 1991).

When treatments were compared in relation to specific time periods post housing there was no significant difference between herds ($p>0.05$) (Table 3.2).

Table 3.2 Comparison of the effect of treatment on locomotion score in relation to time post housing

Period (weeks post housing)	Unit 1		Unit 2		p
	mean	sem	mean	sem	
1 to 7	1.79	0.08	1.79	0.05	0.7
8 to 15	1.78	0.05	1.91	0.05	0.3
16 to 22	1.81	0.06	1.87	0.05	0.5

Effects of calving on locomotion score

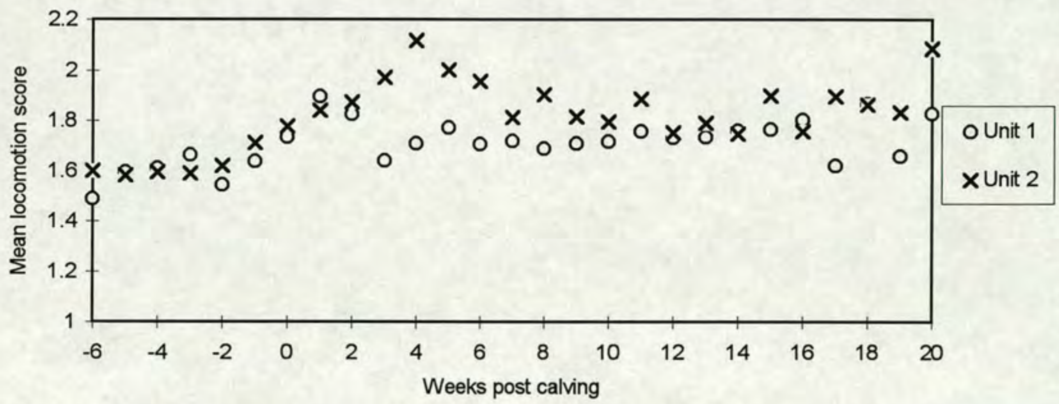
To compare across all groups, data from 6 weeks pre to 20 weeks post-calving were used and analysed by GLM ANOVA. This showed that mean locomotion score was significantly different between first parity cows (1.59 $\pm$0.04) and older cows (1.92 $\pm$ 0.03, $p<0.01$). There was no significant effect of the interaction between treatment calving season and parity ($p>0.05$) (Table 3.3).

Table 3.3 Comparison of mean weekly locomotion score between treatments over the period 6 weeks pre to 20 weeks post-calving

Group	Mean locomotion score	S.E.M
Unit 1 autumn calving heifers	1.61	0.10
Unit 1 spring calving heifers	1.52	0.02
Unit 1 autumn calving cows	1.89	0.10
Unit 1 spring calving cows	1.82	0.05
Unit 2 autumn calving heifers	1.58	0.03
Unit 2 spring calving heifers	1.65	0.15
Unit 2 autumn calving cows	2.09	0.08
Unit 2 spring calving cows	1.89	0.08

Mean locomotion scores for each group were plotted over time (Fig 3.2).

Fig 3.2 Mean locomotion score for each treatment over the calving period



Similar to the analysis of locomotion score with respect to housing, the differences in mean locomotion scores in the 9-11 and the 18-20 week postcalving period from -2-0 week precalving locomotion score were used. There were significant increases in the locomotion scores at 9-11 and 18-20 weeks, compared to the precalving score (n= 120; $p<0.001$) (Wilcoxon statistic 4198 and 3656 respectively).

Calving season had significant effects upon mean locomotion score in the precalving period only (p<0.05) with spring calvers expressing the highest mean scores (Table 3.5). Calving season had no significant effects in any other period however the highest scores were seen between calving and 6 weeks into lactation.

Table 3.5 Effect of calving season on locomotion score across the calving period

Period (weeks post-calving)	Autumn		Spring		
	mean	sem	mean	sem	p
-6 to 0	1.65	0.03	1.76	0.04	**0.03**
1 to 6	2.02	0.07	1.89	0.06	0.9
7 to 12	1.92	0.07	1.77	0.05	0.4
13 to 20	1.92	0.07	1.76	0.08	0.5

3.3.2 Relationship between liveweight, condition and locomotion score post-calving

To relate the effect of production to individual animal body parameters, liveweight and condition measures were correlated against locomotion score. Due to the large numbers of tests on the same data the level of significance was set at the 1% level, although in the following tables an indication is also given if probability reached the 5% level. The pre and post-calving periods were divided up into 3 periods: weeks 1 to 6 (period 1), weeks 7 to 12 (period 2) and weeks 13 to 20 post-calving (period 3). The mean locomotion score was calculated in each period for every animal. The relationship between mean locomotion score in each period and liveweights and condition scores at 0, 4 and 8 weeks post-calving, together with liveweight and condition changes at 4 and 8 weeks post-calving were analysed using Spearman rank correlations. In addition the relationship between locomotion score pre-calving and locomotion score post-calving was investigated by correlating mean locomotion score over the 6 week pre-calving period with mean locomotion scores in each of the above periods.

Comparison between all animals

Spearman rank correlations were made across all animals (Table 3.7). Across all animals, mean locomotion score post-calving was strongly correlated with locomotion score before parturition and liveweight at 0, 4 and 8 weeks post-calving. There was no significant correlation between locomotion score and either liveweight change or condition score post-calving.

Table 3.7 Rank correlations between locomotion score post-calving (PC) and individual cow variables i.e. locomotion score prior to calving, liveweight and condition

All animals (n=136)	Period 1		Period 2		Period 3	
	r	sig.	r	sig.	r	sig.
Mean locomotion score 6 weeks pre calving	0.46	**	0.48	**	0.34	**
Liveweight at calving	0.37	**	0.40	**	0.38	**
Liveweight 4 weeks PC	0.34	**	0.28	**	0.40	**
Liveweight 8 weeks PC	0.37	**	0.38	**	0.44	**
Liveweight change 4 weeks PC	0.12		0.14		0.05	
Liveweight change 8 weeks PC	0.05		0.04		-0.04	
Condition score at calving	-0.01		-0.03		-0.04	
Condition score 4 weeks PC	0.01		-0.01		-0.09	
Condition score 8 weeks PC	0.05		0.04		-0.08	
Condition change 4 weeks PC	-0.09		-0.10		0.08	
Condition change 8 weeks PC	-0.20	•	-0.19	•	0.01	

(•= $p<0.05$; **=$p<0.01$)

Lactation number

Across all animals, lactation number (i.e parity) was positively correlated with initial weight at calving and locomotion score both precalving and in period 1, but not period 2 post-calving (Table 3.8). Lactation number is a rough approximation of the animal's maturity and age.

Table 3.8 Spearman's rank correlation coefficient between lactation number and liveweight and between lactation number and locomotion score (n=136)

	Rank correlation coefficient	Significance
Liveweight at calving	0.456	***
Liveweight 4 weeks post calving	0.406	***
Liveweight 8 weeks post calving	0.426	***
Mean locomotion score 6 weeks pre calving	0.281	**
Mean locomotion score period 1	0.271	**
Mean locomotion score period 2	0.238	•

(•= $p<0.05$; **= $p<0.01$; ***= $P<0.001$)

Comparison between units

Rank correlations were made across animals within each unit (Table 3.9). Similar to the analysis across all animals, there was a significant relationship between locomotion score and liveweight over the initial 8 week period. This was particularly evident for unit 1, however there were fewer significant correlations over the same periods for unit 2 although the trend was similar. Locomotion score within units was not correlated with any of the liveweight change or condition score variables.

Table 3.9 Rank correlations between locomotion score post-calving (PC) and locomotion score prior to calving, liveweight and condition score. Comparison between units

	unit 1 (n=67)						unit 2 (n=69)					
	Period 1		Period 2		Period 3		Period 1		Period 2		Period 3	
	r	sig.	r	sig.	r	sig.	r	sig.	r	sig.	r	sig.
Mean locomotion score 6 weeks pre calving	0.48	**	0.62	**	0.42	**	0.46	**	0.35	**	0.31	•
Liveweight at calving	0.37	**	0.45	**	0.38	**	0.32	**	0.34	**	0.33	**
Liveweight 4 weeks PC	0.37	**	0.41	**	0.42	**	0.27	•	0.28	•	0.29	•
Liveweight 8 weeks PC	0.38	**	0.42	**	0.43	**	0.28	•	0.32	**	0.35	**
Liveweight change 4 weeks PC	0.07		0.14		-0.01		0.21		0.2		0.14	
Liveweight change 8 weeks PC	0.09		0.17		0.03		0.08		-0.01		0.09	
Condition score at calving	-0.05		-0.07		-0.07		0.02		-0.01		-0.03	
Condition score 4 weeks PC	-0.04		-0.02		-0.15		0.02		-0.03		-0.08	
Condition score 8 weeks PC	-0.03		0.01		-0.16		0.07		0.01		-0.07	
Condition change 4 weeks PC	-0.06		-0.12		0.20		-0.01		-0.05		0.09	
Condition change 8 weeks PC	-0.12		-0.17		0.12		-0.24		-0.16		-0.08	

(•= $p<0.05$; **=$p<0.01$)

Comparison between calving season

Rank correlations were made across animals within each calving season (Table 3.10). Within calving season, locomotion score post-calving was correlated with liveweight post-calving, but not with liveweight change. There was no significant relationship between locomotion score post calving and condition score.

Table 3.10 Rank correlations between locomotion score post-calving (PC) and locomotion score prior to calving, liveweight and condition. Comparison between calving season

	Autumn calving animals (n=68)						Spring calving animals (n=68)					
	Period 1		Period 2		Period 3		Period 1		Period 2		Period 3	
	r	sig	r	sig	r	sig	r	sig	r	sig	r	sig
Mean locomotion score 6 weeks pre calving	0.45	**	0.42	**	0.42	**	0.50	**	0.56	**	0.36	**
Liveweight at calving	0.44	**	0.45	**	0.49	**	0.33	**	0.37	**	0.25	•
Liveweight 4 weeks PC	0.41	**	0.43	**	0.55	**	0.30	•	0.32	•	0.23	•
Liveweight 8 weeks PC	0.42	**	0.46	**	0.57	**	0.32	•	0.33	**	0.29	•
Liveweight change 4 weeks PC	0.24		0.13		0.04		0.04		0.17		0.09	
Liveweight change 8 weeks PC	0.11		0.03		-0.03		0.05		0.12		-0.05	
Condition score at calving	-0.07		-0.16		-0.21		0.02		0.06		0.07	
Condition score 4 weeks PC	-0.02		-0.10		-0.24	•	0.03		0.06		-0.01	
Condition score 8 weeks PC	-0.02		-0.06		-0.27	•	0.10		0.12		0.04	
Condition change 4 weeks PC	-0.21		-0.20		0.05		0.01		-0.01		0.10	
Condition change 8 weeks PC	-0.20		-0.22		0.04		--0.21		-0.15		-0.03	

(•= $p<0.05$; **=$p<0.01$)

3.3.3 Incidence and distribution of lameness diseases 1995-1996

Total numbers of individual lame cows examined over the study period are given below; these included animals that presented 2 or more cases of lameness (Table 3.11). There was no significant difference between units in terms of overall numbers of lame animals (χ^2=0.58, p>0.05).

Table 3.11 Total numbers of lame animals

System	# of individuals	% of herd
unit 1	31	35
unit 2	36	40
Total	67	38

To define incidence as the number of new cases or the number of new lesions over the study period we needed to determine whether any animals were lame in the 42 days before the start of the study period. In this period (July/ August 1995), 3 animals were lame and were treated. Two of these animals did not show lameness in the study period however one did subsequently become lame but this was approximately 22 weeks into the study and therefore it was classed as a new case.

The actual distribution of lesions from each case over the study period is shown below in Table 3.12. There was difficulty in some cases in establishing which lesion was contributing most to the lameness. In these situations the most severe lesions (2 or even 3) were included. In addition the data included cases from the same animal at different times.

Table 3.12 Distribution and extent of lesions causing lameness categorised by disease

Disease	Unit 1	Unit 2	Units combined
Severe horn haemorrhage♠	9	11	20
Sole ulcer	15	11	26
Underrun (wall and sole)	4	7	11
Septic penetration	11	8	19
Wall separation✞	2	2	4
Interdigital dermatitis	11	31	42
Foul	3	16	19
Digital dermatitis	9	19	28
Miscellaneous	2	2	4
Total	66	107	173

(♠Haemorrhages scoring 4 or above; ✞ severe underrunning of wall with exposed corium)

The Chi squared test was used to compare the number of lesions in each disease category between treatments. Some of the diseases had low numbers of lesions especially in unit 1, therefore these diseases were grouped into larger categories for analysis. Underrun and miscellaneous diseases were grouped into a category called other, whilst foul and interdigital dermatitis were grouped into interdigital disease (Table 3.13). Severe horn haemorrhages, sole ulcers, septic penetrations and wall separation are considered to be of similar origin and were grouped into the category "severe claw horn disruption" (**SCHD**) (Table 3.13). Cows on unit 1 had a significantly higher number of SCHD lesions whilst those on unit 2 showed a significantly higher numbers of interdigital disease lesions. Overall there was a significant difference between units as animals in unit 2 presented more lesions causing lameness over the study period (p=0.004).

Table 3.13 Comparison of lesions causing lameness between treatments

Disease	unit 1		unit 2				
	observed	expected	observed	expected	d.f	χ^2	SIG
SCHD	37	26.3	32	42.6	1	7.0	p< 0.01
Interdigital disease	14	23.3	47	37.7	1	5.98	p< 0.05
Digital dermatitis	9	10.7	19	17.3	1	0.43	n.s
Other	6	5.7	9	9.3	1	0.02	n.s
Total	66		107		5	13.4	p=0.004

The distribution of lameness lesions between the fore and the hind claws showed that the majority of cases were centred in the hind claws (Table 3.14). However this difference was not significant by χ^2 test.

Table 3.14 Distribution of lesions between front and hindfeet

	unit 1	%	unit 2	%	Units combined	%
Hindfeet	56	87.5	90	86	150	87
Forefeet	8	12.5	15	14	23	13
Total	66		107		173	

The distribution of infectious and non infectious lameness lesions within each unit are shown in Figs 3.3 to 3.6 over the period of August 1995- July 1996 (AC=autumn calvers, SC=spring calvers). Autumn calvers had more lesions over the study period compared to spring calvers (102 vs 73).

Fig 3.3 Incidence & distribution of non- infectious lesions within unit 1 (AC=autumn calvers, SC=spring calvers)

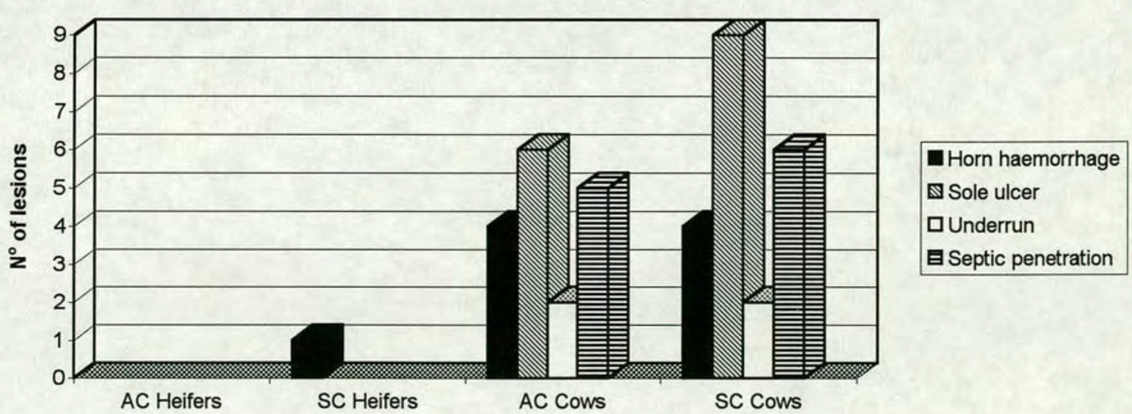


Fig 3.4 Incidence & distribution of non infectious lesions within unit 2 (AC=autumn calvers, SC=spring calvers)

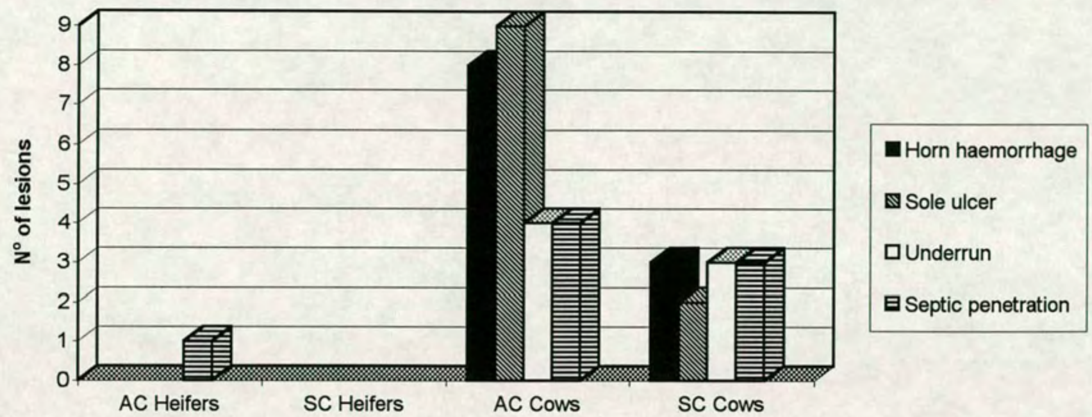


Fig 3.5 Infectious lameness lesion distribution within unit 1 (AC=autumn calvers, SC=spring calvers)

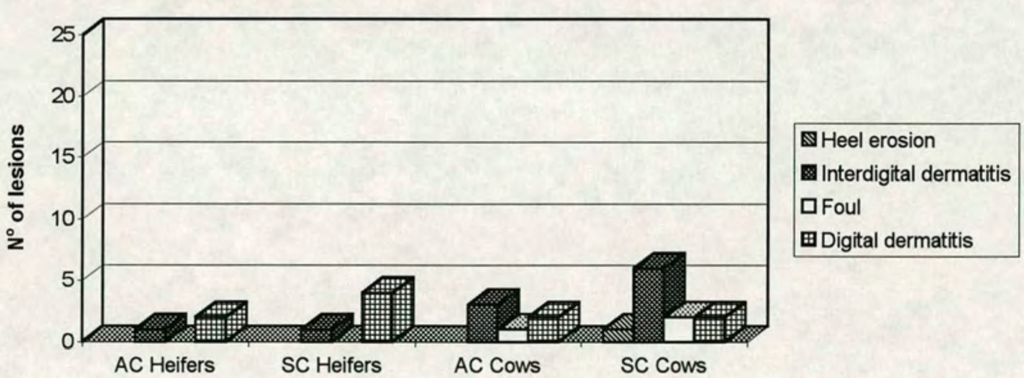
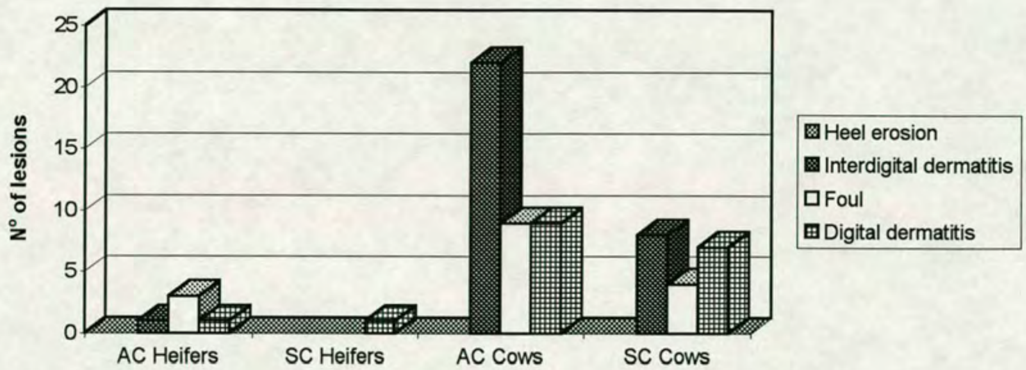


Fig 3.6 Infectious lameness lesion distribution within unit 2 (AC=autumn calvers, SC=spring calvers)



3.4 Discussion

3.4.1 Parity and calving season effects

The effects of parity and calving upon locomotion score were marked. Heifers had significantly lower locomotion scores compared to older animals. It is suggested that the heifers were at lower lameness risk than older animals, having not yet passed through a complete housing/lactation period, where they would be exposed to all major lameness risk factors. Furthermore if an animal had received an insult sufficient to cause lameness in a previous lactation there would be an increased likelihood of developing lameness in the current lactation (Enevoldsen *et al*, 1991a; Ward & French, 1997). Such an effect is presumably due to irreparable damage to the corium, or these cows have a genetic predisposition for hoof characteristics which are more susceptible to lameness. Older animals would therefore be expected to present more cases of lameness than first lactation animals, accounting for the higher median locomotion scores seen in this group over the housing period.

The animals which showed the highest locomotion scores in relation to calving were the autumn calving cows within unit 2. This was attributable to an outbreak of foul that occurred soon after the animals' were housed starting in early October and continuing until mid January.

As locomotion score is a mobility score, there may be other influences on the gait of older cows not directly attributable to lameness. Cows which had completed their first lactation have larger udders in subsequent lactations partly due to their increasing yield and partly due to irreversible stretching of the supportive connective tissue of the udder (Webster, 1995). A larger udder interferes with the gait of the animal, making her splay the legs outward and reduce the stride length considerably. This may bias the observer into giving an unduly high score to such an animal. Such an influence on locomotion score cannot be ruled out even though measures were taken to reduce this possible effect by scoring the animals immediately post milking when the influence of udder size on gait would be minimised. However a component of the higher locomotion score shown by the cow groups compared to the heifer groups may be accounted for by this effect.

Calving had a significant effect over time. Locomotion scores 10 and 20 weeks postcalving were significantly higher than a precalving score. Locomotion scores postcalving were variable which suggests that the effect of calving on mobility was not uniform presumably due to the animals changing susceptibility to the various risk factors occurring around this period.

3.4.2 Housing and parity effects

Within the Acrehead system, housing appeared to have conflicting effects on locomotion score. The analysis segregated heifers from older animals. Unit 1 spring calving heifers had the lowest locomotion scores in relation to housing whilst unit 2 autumn calving cows had the highest. Again this was presumably due to the foul "outbreak". The effect of parity has been discussed previously: heifers still have to undergo a full housing/lactation period and are at a reduced lameness risk.

Housing appeared to be a significant risk factor in the development of lameness as locomotion scores after 10 and 20 weeks of housing were significantly higher than the initial prehousing score. Thus prolonged exposure to the various risk factors associated with housing (e.g. concrete, slurry) increased the locomotion score of cows.

Within each unit the autumn calving cows have significantly higher locomotion scores than spring calving cows. Autumn calvers are exposed to 2 major risk factors - calving and housing, within a very short period of time, i.e. 2-3 weeks. It is suggested that these factors probably have additive effects on the development of lameness diseases and as a result autumn calvers would be expected to present more cases of lameness expressed as an increased locomotion score. Autumn calvers did present more lesions causing lameness than did spring calving cows. Conversely spring calvers are subjected to the risk factors of housing (e.g concrete and slurry) approximately 2 months prior to calving, then there appears to be either a beneficial effect of earlier housing "exposure" or that it occurs at time when its risk is considerably reduced. By exposure we mean "acclimatising" the animals to the various conditions of housing, in terms of the claw growth and wear on concrete and behavioural adaptation: feeding from feed face, cubicle use and social structure under confined conditions. If these factors are considered stressful for the cow, it is probably better if they do not occur around the crucial time of calving. It would therefore be prudent to allow an adequate adaptation period for autumn calving animals on exposure to housing to prevent this additive effect.

3.4.3 Effects of liveweight, condition score and locomotion score pre-calving on locomotion score post-calving

Liveweight appeared to have strong influences on locomotion score across all animals, within treatments and within season. Locomotion score was strongly positively correlated with liveweight at 0, 4 and 8 weeks post-calving. This could mean either that heavier animals were more prone to developing lameness disease because they are placing increased pressure on their hooves or more likely that the heavier animals consisted of the oldest animals in the herd and would therefore be at an increased lameness risk, manifesting itself as a higher locomotion score. This is confirmed by the fact that liveweight and locomotion score were strongly correlated both pre and post-calving with lactation number. Intriguingly liveweight change was not associated with locomotion score so presumably mobility is not affected by the weight change removed off the hooves during early lactation. This lack of correlation may have been accounted for by the different weight change between units (% liveweight lost from initial postcalving weight, Unit 1=9.6 % vs Unit 2= 7.4%; $p<0.05$). The less weight lost in unit 2 (the higher lameness incidence herd) and the more weight lost in unit 1 (the lower lameness incidence herd) would in some way explain the non significance of the correlation between weight change and locomotion score.

Condition score was not correlated with locomotion score across all animals or within treatments or season. As condition score is classed on an ordinal scale there were many tied ranks during the rank correlation analysis which may have a large influence on the difference between the majority of animals.. Animals which lost most condition included the heifers and most animals within unit 1, as these animals also had the lowest locomotion scores which maybe reflects a coincidental relationship between the effects of treatment on condition and locomotion score respectively.

Locomotion score prior to parturition

Locomotion score in the immediate precalving period correlated positively with locomotion score in the 20 week post-calving period across all animals and within treatment and season. A relatively high locomotion score pre-calving could have indicated a high level of subclinical disease or the effects of a lameness insult in the prior lactation. If this is the case then these animals were likely to develop lameness disease, increasing locomotion score.

3.4.4 Incidence of lameness disease.

The actual numbers of individual animals becoming lame over the study period within each unit did not differ significantly between treatment, however the number of lesions causing lameness was significantly higher within unit 2, the high dietary input unit. The distribution of lesions concentrated specifically in the hind feet, with over 80% of all cases being located there. This is in agreement with previous studies of lameness incidence (Arkins, 1981).

Unit 1 presented more lesions associated with severe claw horn disruption especially sole ulcer whereas unit 2 presented more infectious interdigital lesions. The majority of the interdigital disease seen was due to an outbreak of foul within unit 2, the high input herd, early in the housing period. The difference between units primarily concerned the early stage of housing. Unit 1 was allowed a period of extended grazing. In some way this may have protected these animals from contracting infectious disease possibly because the interdigital space was cleaned on a regular basis by the animals walking across long pasture on a daily basis. In fact cases of foul were only seen within unit 1 animals when the period of extended grazing ceased. Overall unit 2 presented more clinical cases of lameness mainly because of the higher incidence of foul and interdigital disease.

The distribution of disease within each unit demonstrates that the heifer groups did not present many lesions and consequently expressed the lowest locomotion scores.

In conclusion, treatments apparently affected the incidence of lameness and the expression of locomotion score. However over the study period, comparable groups of animals in each unit showed remarkably similar responses in terms of locomotion score to the housing and calving periods: perhaps these factors are more important than treatment in the short term in increasing locomotion score, which can be used as an indicator of lameness development.

4 Effects of management and diet on cows' activity budgets

4.1 Introduction

Many studies have observed the effects of manipulating the immediate environment on the behaviour of dairy cows. In previously published studies, factors such as group size, cubicle allowance and passage width have been investigated (Arave & Albright, 1981; Metz & Wierenga, 1987; O'Connell *et al*, 1989). However, there have been few studies that have investigated the effect of manipulating management and production but maintaining consistent housing, group size and herd composition factors. Jackson *et al* (1991), fed diets containing a concentrate based on either fibre or starch to manipulate energy levels; they found no difference in feeding frequency or total feeding time between animals on the two diets.

Cattle are very effective at adapting their ingestive behaviour to meet physiological and environmental changes. In the U.K the use of grass silage based rations has been the standard practice. Such feeding regimes utilise low energy, wet forage which is difficult to consume in large quantities. Diets of this type may alter the animals' activity budgets as cows have to stand for increasing periods of time to achieve adequate energy intake.

At Acrehead, altering the provision of concentrates between units during lactation has resulted in production differences between these herds (see chapter 2). Genetically all cows had similar production potential; unit 1 animals therefore were essentially having to achieve their production on a very fibrous, relatively low energy ration whilst unit 2 cows were fed to maximise their yield by being offered a greater amount of concentrate.

An investigation of whether the dietary treatments had an effect on the activity budgets of dairy cows was conducted. The possible dietary influences are thought to be mediated through the physical effects the diets have on maintenance behaviours, particularly feeding and lying times. The secondary effect of calving season on the expression of behaviour at different stages within the housing period was also investigated.

4.2 Materials and methods

4.2.1 Animals

Groups I (year 1 94/95) and II (year 2 95/96) were used in this experiment and data from each year was analysed independently. The groups comprised heifers and second lactation cows from each unit. All second lactation cows from each herd were used as these animals had their feet regularly examined during their first lactation therefore their previous lesion history was known. Thirty animals were observed during year 1 and 56 during year 2 roughly divided between calving season and treatment. The complete breakdown of animals by lactation and season is given in chapter 2. All first calving heifers within each herd were used to provide the maximum sample size possible. Heifers are useful as a study animal because they do not have damage to the feet from earlier lactations. The second parity animals surviving from the first year were also used as a complete lesion history from the first lactation was available.

4.2.2 Housing & diets

Detailed descriptions of housing and feed rations are provided in chapter 2. Over lactation approximately 0.5 t and 1.5t of concentrate was fed to each animal in unit 1 and unit 2 respectively. In addition the twice daily milking regime was changed for unit 2 in the second year, so that animals received thrice daily milkings. Animals were housed in a conventional cubicle system with Newton Rigg cubicles. The diets were different between years; however unit 1 was required to "cope" with a lower concentrate, higher fibre diet (see appendix).

4.2.3 Experimental procedure

The study occurred over 2 years duration where production and management was manipulated on each unit between years. In year 1, observations were conducted on heifers only and no observations on the autumn calving animals were made prior to parturition. During the following year, first and second lactation animals were observed both prior to and post parturition.

4.2.4 Behavioural observation

Records of 24 hour activity were made using a 10 or 15 minute scan sampling technique. Data was collected by conducting three 4 hour observation periods daily over five days so that two replicates of any particular time in the day were obtained. General procedure and dates of the behavioural watches in years 1 and 2 are given in chapter 2. The majority of the observations were conducted over the weekend to get comparable behavioural records of each herd without disruption by stockmen which was unpredictable. The behavioural observations had their emphasis on collecting comparable behaviour between herds the results of which however may not be representative of the behaviour of cattle throughout the week Time engaged in various behaviours were expressed as % of scans for all watches pooled.

4.2.5 Statistical analysis

All observations were analysed using Minitab version 5 for mainframe use (Anon, 1991). Behavioural data was initially analysed using principle component analysis to identify the major behavioural categories accounting for the variance. These were standing behaviours (inactive, ruminating, feeding, walking) and lying behaviour (inactive and ruminating). These identified categories were then further analysed using general linear model ANOVA. Plots of the actual values and residuals showed that there was a normal distribution for each behavioural variable within each watch, and in fact general linear models are robust enough to deal with less than normally distributed data. No transformation of the data was therefore required. The model had 1 main treatment and 2 blocks each of 2 levels: Treatment- unit (1 or 2); Block 1- calving season (autumn or spring); Block 2- parity (1st or 2nd). The interaction between treatment and block as well as a covariate effect of weeks post-calving was included in the model as a positive or negative integer. All behaviours are expressed as % of scans. Year 1 was analysed separately from year 2.

Due to the large numbers of watches, a repeated measures ANOVA could not be performed, as models are limited to a maximum of 6 time periods, therefore each watch was analysed separately. Due to the same test being performed on each watch the criterion of significance was changed to 1% to reduce the likelihood of spurious significant results.

The problem of replication is a persistent one in this thesis. There are only two treatments with no controls and as management changed from year 1 to 2 (namely diet, milking regime and parity of experimental groups) it was not possible to analyse the data between years comparing each data set as a replicate. The changes in activity following calving agree with work by Ruckebusch (1975) and daily activity patterns were not dissimilar to other work that progressed after the completion of this trial (Chaplin 1997, pers. comm.) or from a small pilot study using heifers conducted roughly at the same time as the year 1 behavioural watches.

The behaviours defined were likely to be interrelated, therefore to obtain a clearer insight into the structure of the behavioural data, factor analysis was performed. Factor analysis allows complex interrelationships between a large number of variables to be reduced to a considerably smaller number of underlying factors that account for a large proportion of the variance in the original variables (Hedderson, 1987; Martin & Bateson, 1993). Principal component analysis was performed on all the behaviours to identify the most important behavioural variables and to determine how many factors to calculate from the eigenvalues. The number of factors to calculate was taken as the number of principal component eigenvalues that equalled 1 or more. Analysis was performed using Minitab Version 10 for Windows using a varimax factor rotation (default option). Rotating the factors is a method of simplifying cross loading variables so that the variable loads highly in one factor only (Frey & Pimental, 1978; Manly, 1986). Factor scores were calculated for each animal and subsequent analysis was performed using GLM ANOVA, again in Minitab.

4.3 Results

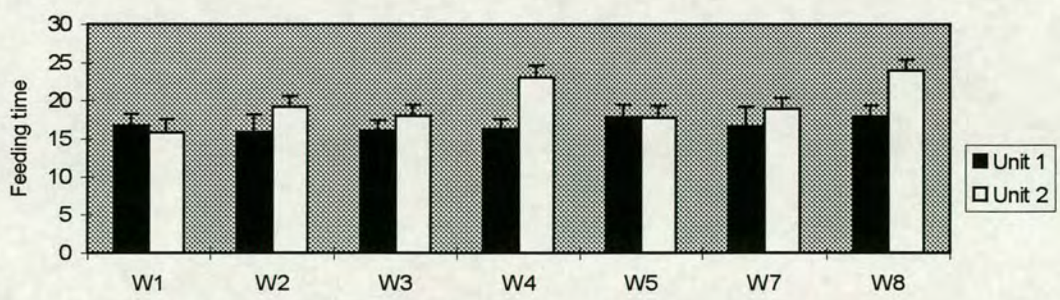
4.3.1 Year 1

The differences between treatments in year 1 were not significant due to the fairly similar management procedures. There was no significant effect of a days post-calving covariate on any of the following behaviours ($p>0.05$). However there were some differences between treatments in specific behaviour patterns in certain watches. Due to the low numbers of spring calving animals the effect of calving season was not included in the ANOVA model but a week's post-calving covariate was assigned for all animals.

Feeding behaviour

There were no significant differences in feeding time between units in any watch ($p>0.01$) (Fig 4.1). The overall trend was for a slightly longer feeding time in unit 2 compared to unit 1 (unit 2=19.1%, sem 1.2 vs unit 1=15.6%, sem 2.7).

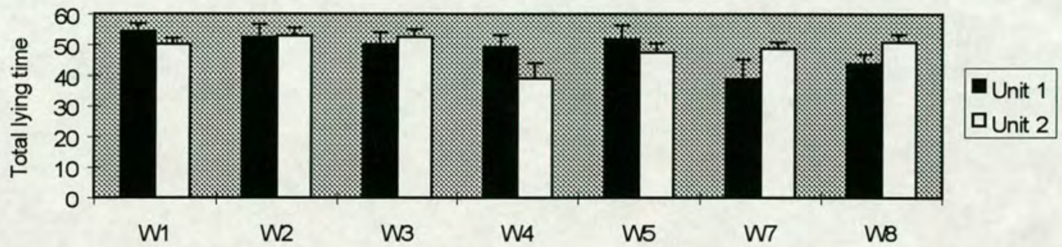
Fig 4.1 Feeding time of each treatment over all watches (% of scans)



Lying times

Total lying time, i.e. the sum of lying inactive and lying ruminating, did not differ significantly between treatments over the study period (Fig 4.2). The overall means were 47.6% (sem 1.93) and 47.7% (sem 1.75) for units 1 and 2 respectively.

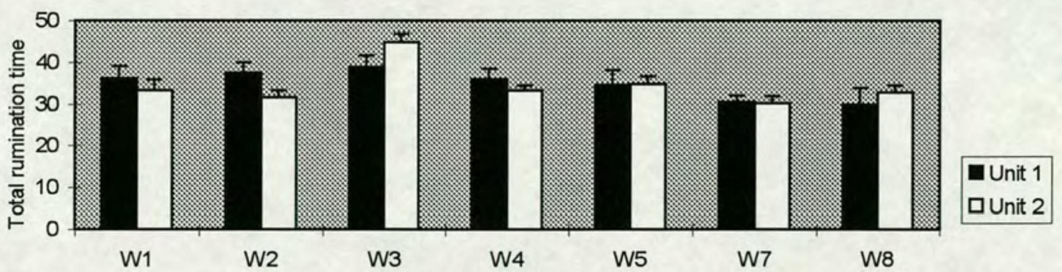
Fig 4.2 Total lying times on each treatment (% of scans)



Rumination

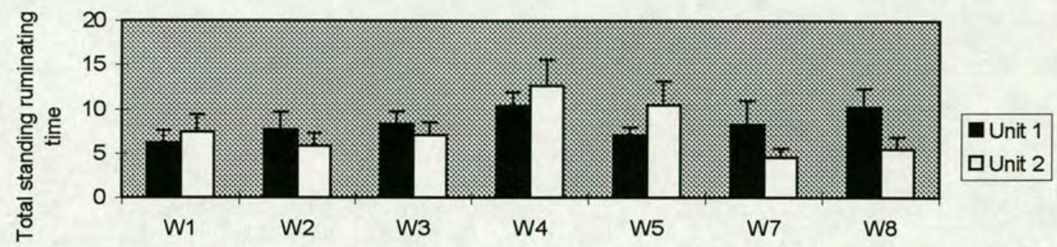
There was no significant difference between treatments in any watch ($p>0.01$) (Fig 4.3). Overall there was no apparent difference between the two units (unit 1= 33.3 sem 0.79 vs unit 2 = 35.1 sem 0.86).

Fig 4.3 Total rumination time between treatments (% of scans)



There was no significant difference between units in terms of total time spent standing ruminating in any watch ($p>0.01$) (Fig 4.4).

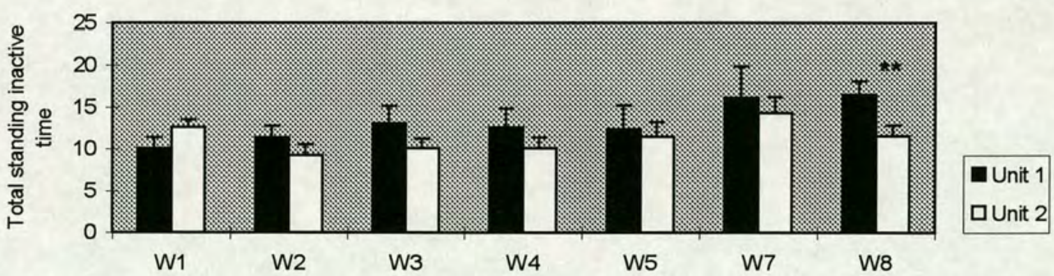
Fig 4.4 Comparison of total standing ruminating time between treatments (%of scans)



Standing inactive

Unit 1 stood inactive for a significantly longer proportion of time in watch 8 ($p<0.01$) (Fig 4.5). Over all watches unit 1 tended to spend more time standing inactive compared to unit 2.

Fig 4.5 Time spent standing inactive on each treatment (% of scans)



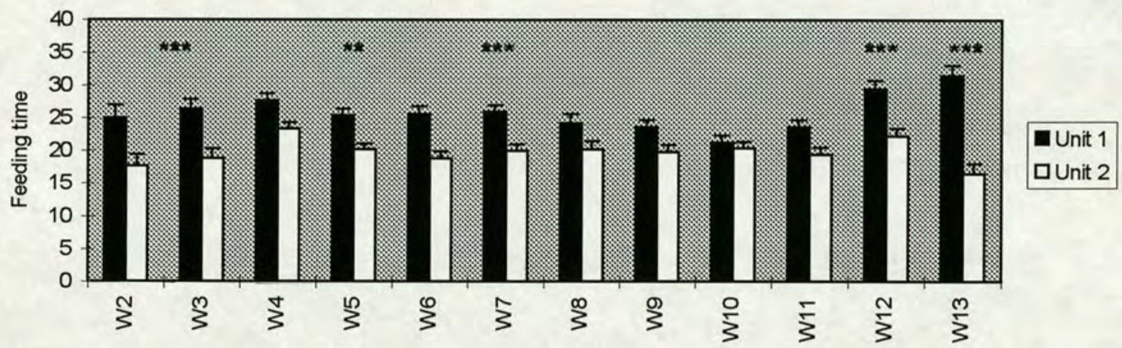
4.3.2 Year 2

Watches 2 to 13 inclusive were used in comparing behaviour between treatments. The majority of the spring calving animals were not housed until watch 5; comparisons between seasons (i.e. autumn and spring calvers) within treatments have therefore been made across watches 5 to 13.

Feeding time

There was a significant effect of treatment on feeding time (p<0.01). Unit 1, the low input herd, spent longer feeding than did unit 2 animals in 5 watches (Fig 4.6). Overall unit 1 fed for longer than unit 2 (unit 1=25.7%, sem 0.79 vs unit 2=19.8%, sem 0.52).

Fig 4.6 Comparison of feeding time (% of scans) between treatments



Unit 1 autumn calving animals fed for longer in most watches and for significantly longer in watches 5, 9 and 10 compared to unit 1 spring calving animals (Fig 4.7). Within unit 2, there was no significant feeding time difference between calving season (p>0.01) (Fig. 4.8).

Fig 4.7 Comparison of feeding time (% of scans) between calving season within unit 1

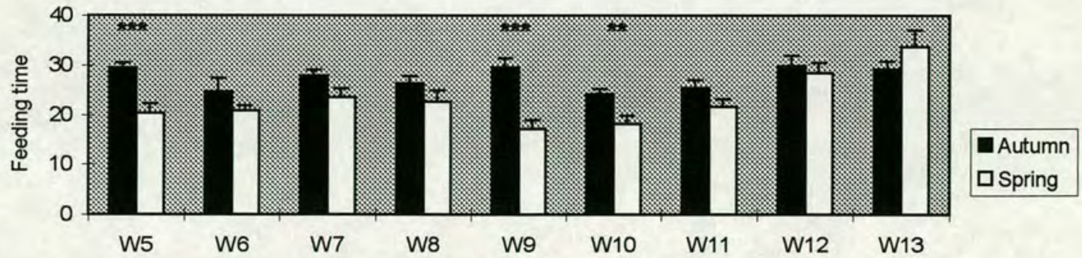
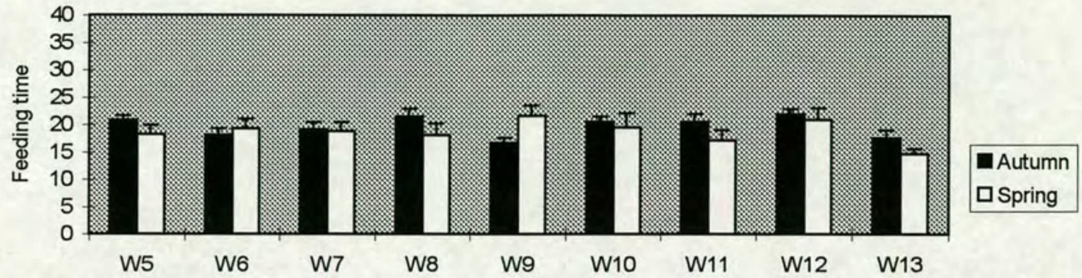


Fig 4.8 Comparison of feeding time (% of scans) between calving seasons within unit 2

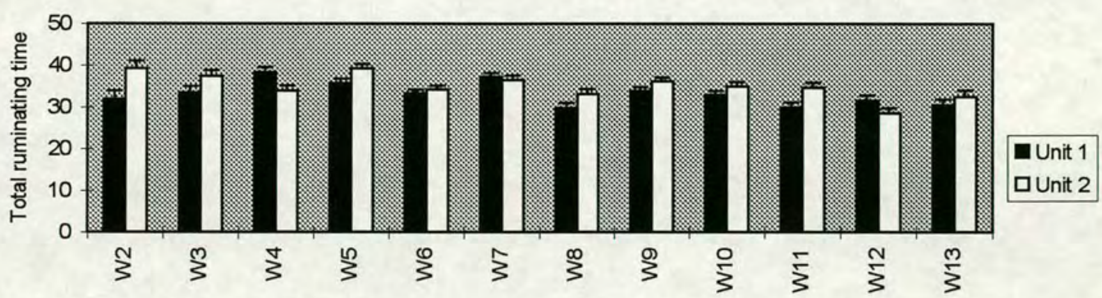


Feeding time did not differ significantly between heifers and cows within each unit or across all watches (p>0.05).

Rumination

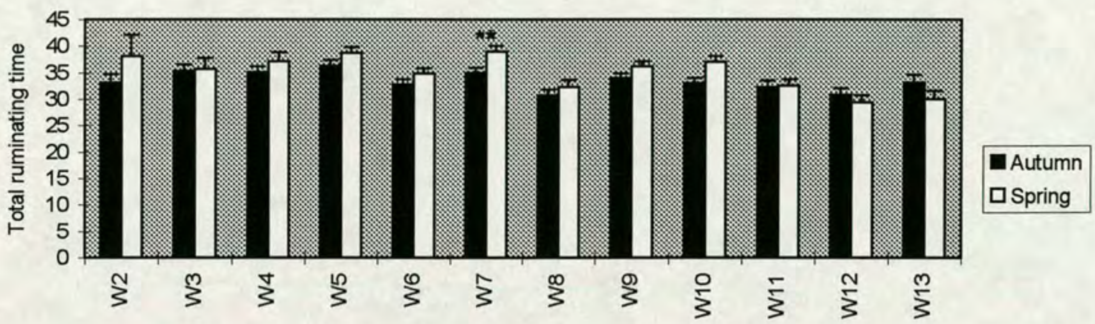
Total rumination time, i.e. the sum of all standing and lying rumination behaviour did not differ significantly between treatments in any watch (p>0.01) (Fig 4.9). Overall the comparison between the low and the high input units was; unit 1= 33.3%, sem 0.79 vs unit 2 = 35.1%, sem 0.86.

Fig 4.9 Comparison of total rumination time (% of scans) between treatments



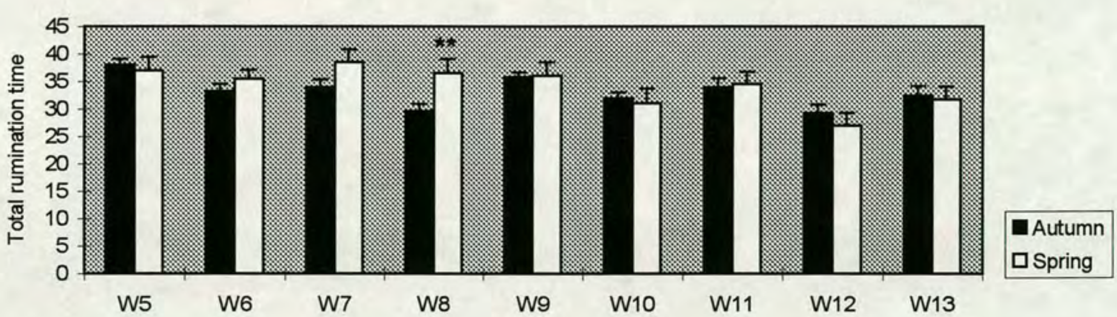
Unit 1 spring calving animals, compared to autumn calvers, had a significantly higher total rumination time in watch 7 only (p<0.01) (Fig 4.10). Overall however there was very little difference between autumn and spring calvers (autumn= 31.9 %, sem 0.57 vs spring= 33.7%, sem 1.09).

Fig 4.10 Comparison of total rumination time between seasons within unit 1 (% of scans)



Unit 2 spring calving animals had a significantly higher total rumination time than autumn calvers in watch 7 (Fig 4.11). Overall, however, there was little difference between autumn and spring calvers (autumn= 32.7%, sem 0.85 vs spring= 34.3%, sem 1.17).

Fig 4.11 Comparison of total rumination time between seasons within unit 2



There was a significant calving season effect on total standing ruminating time both inside and outside of the cubicles. Unit 1 spring calvers stood and ruminated longest in watches 6 and 9 (p<0.01) (Fig 4.12), whilst within unit 2 spring calvers stood and ruminated for longest in watch 8 (Fig 4.13). Overall in both units autumn calvers stood and ruminated for less time (autumn= 7.26%, sem 0.47 vs spring= 11.45%, sem 0.7).

Fig 4.12 Comparison of total time spent standing ruminating (% of scans) between calving season within unit 1

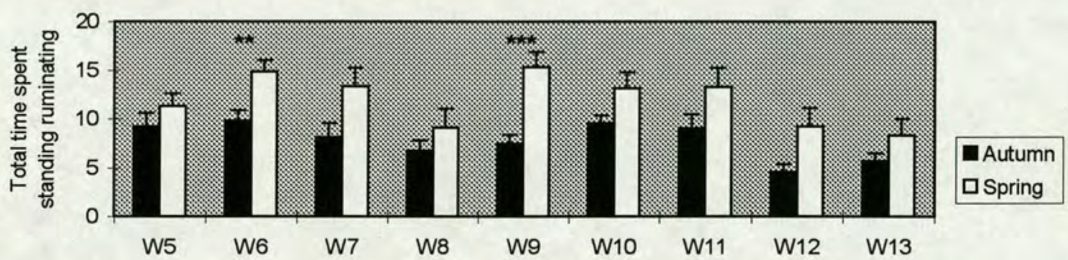
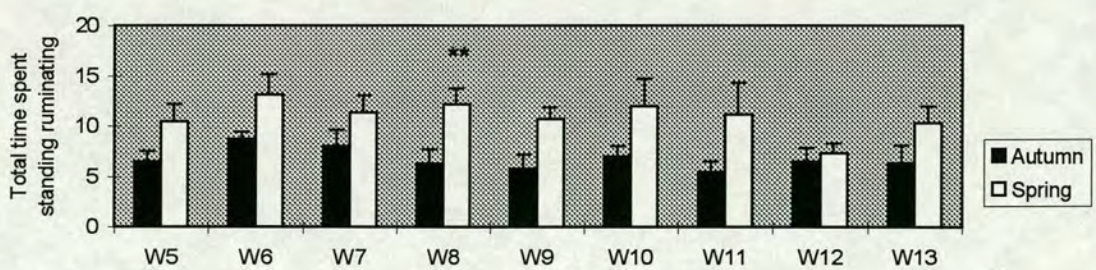
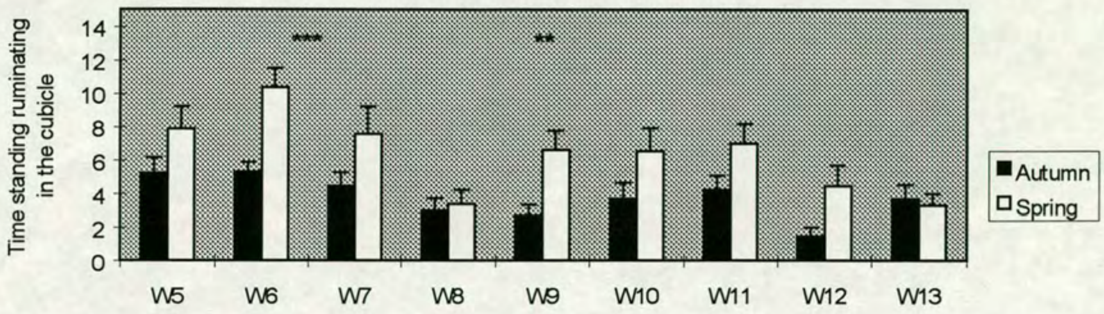


Fig 4.13 Comparison of total time spent standing ruminating (% of scans) between calving season within unit 2



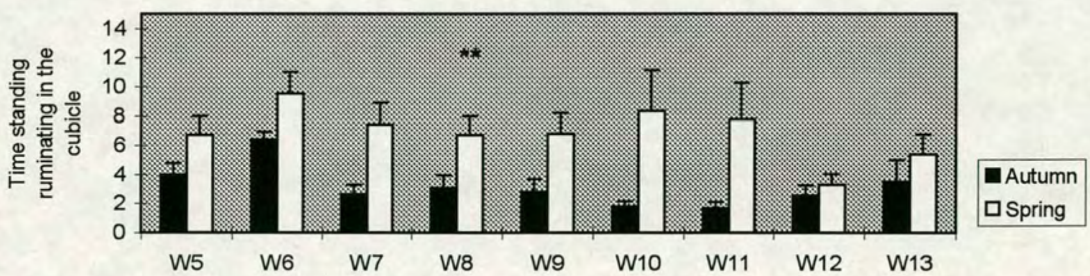
A large proportion of the standing ruminating behaviour was conducted within the cubicles and again calving season had a significant influence on this behaviour within each unit. Unit 1 spring calvers stood and ruminated in the cubicles for significantly longer than autumn calvers in watches 6 and 9 (p<0.01) (Fig 4.14).

Fig 4.14 Comparison of time spent standing ruminating within the cubicles (% of scans) between calving season within unit 1



Unit 2 spring calvers stood and ruminated in the cubicles for significantly longer than autumn calvers in watch 8 ($p<0.01$) (Fig 4.15). Although there was large variation within calving season, in almost every watch spring calvers ruminated longest.

Fig 4.15 Comparison of time spent standing ruminating within the cubicles (% of scans) between calving seasons within unit 2

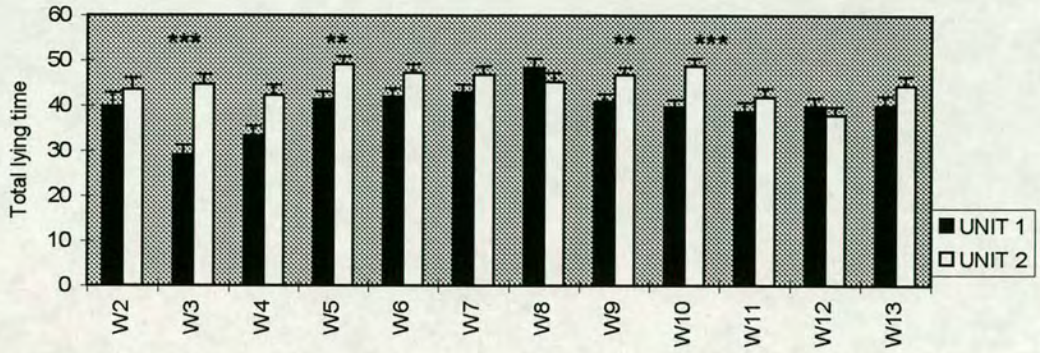


Lying Behaviour

Total time spent lying

Unit 1 spent significantly less time lying in watches 3, 5, 9 & 10 (Fig 4.16).

Fig 4.16 Comparison of total lying time (% of scans) between treatments



Within units, there was no difference between calving season in any watch ($p>0.01$) (Figs 4.17 & 4.18). Heifers spent significantly longer lying in watch 5 only compared to older animals over the same period (Fig 4.19).

Fig 4.17 Comparison of total lying time (% of scans) between calving seasons within unit 1

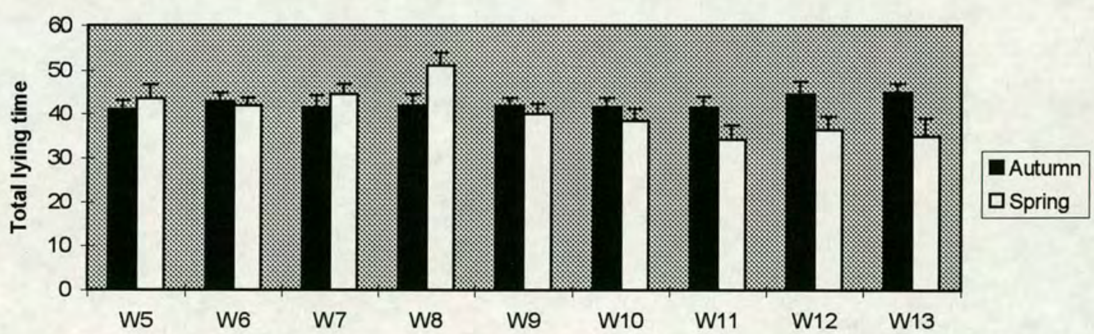


Fig 4.18 Comparison of total lying time between calving seasons within unit 2 (% of scans)

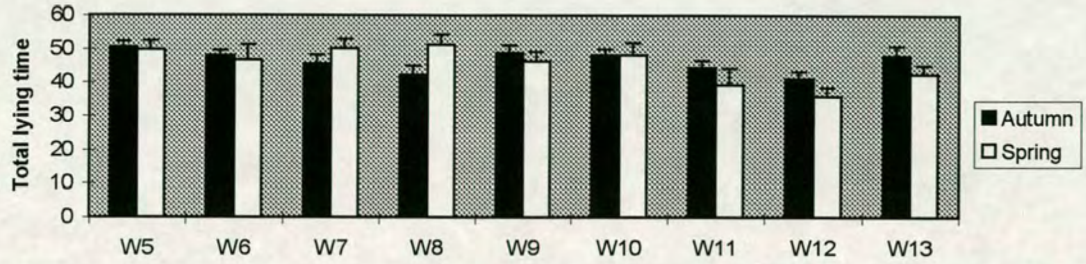
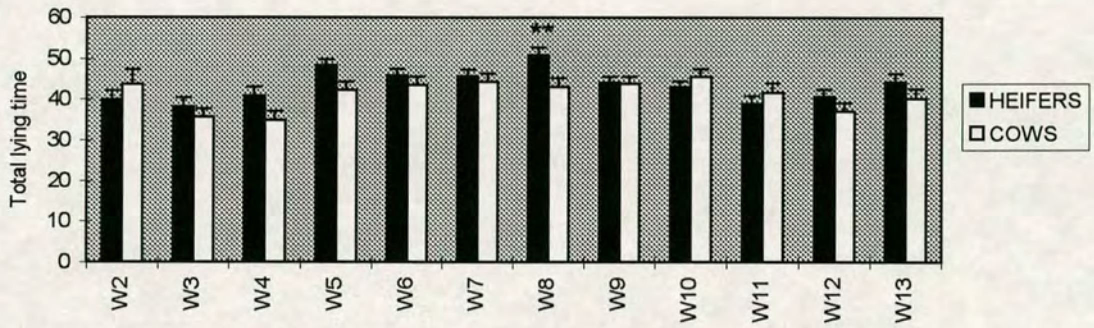


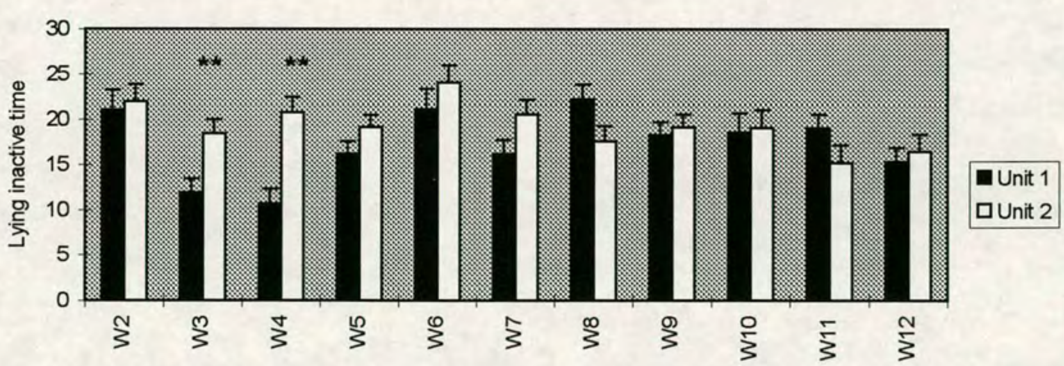
Fig 4.19 Comparison of total lying time (% of scans) between heifers and cows



Lying Inactive

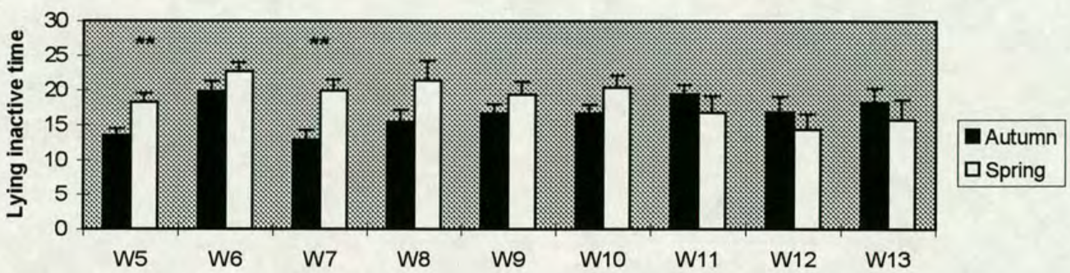
Unit 1 lay inactive for significantly less time in watches 3, and 4 (Fig 4.20).

Fig. 4.20 Comparison of lying inactive time between treatments



Lying inactive did not differ significantly between calving season in unit 2 however within unit 1 autumn calvers lay inactive for significantly longer times in watches 5, and 7 (Fig 4.21). There was no difference between heifers and cows (p>0.01) across all watches.

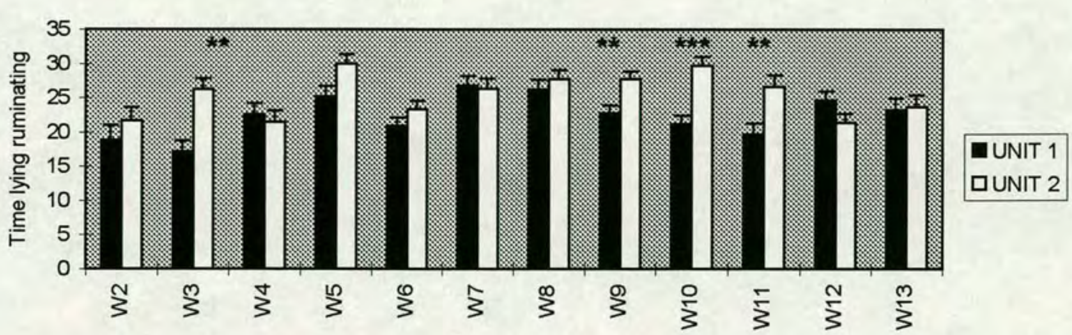
Fig 4.21 Comparison of time spent lying inactive (% of scans) between calving season within unit 1



Lying Ruminating

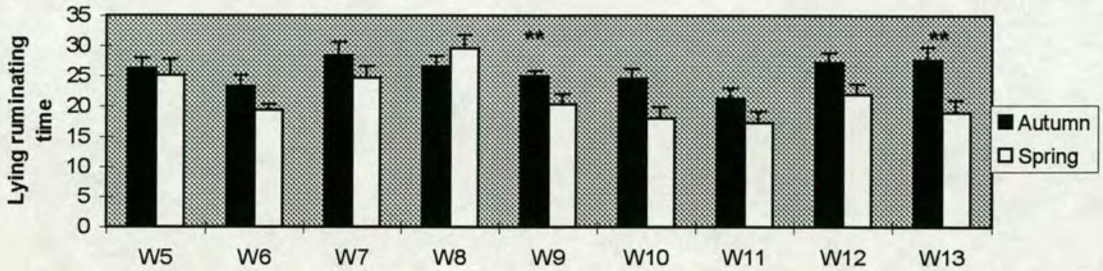
Unit 2 animals spent significantly longer lying ruminating in watches 3, 9, 10 and 11 (Fig 4.22). The overall trend was that unit 2 lay and ruminated for longer (unit 1= 22.5%, sem 0.89 vs unit 2= 25.5%, sem 0.89).

Fig 4.22 Comparison of time spent lying ruminating (% of scans) between treatments



Lying ruminating did not differ significantly between calving seasons in unit 2 (p>0.05), however unit 1 autumn calvers lay ruminating for significantly longer than spring calvers in watches 9 and 13 (p<0.01) (Fig 4.23).

Fig 4.23 Comparison of time spent lying inactive (% of scans) between calving season within unit 1

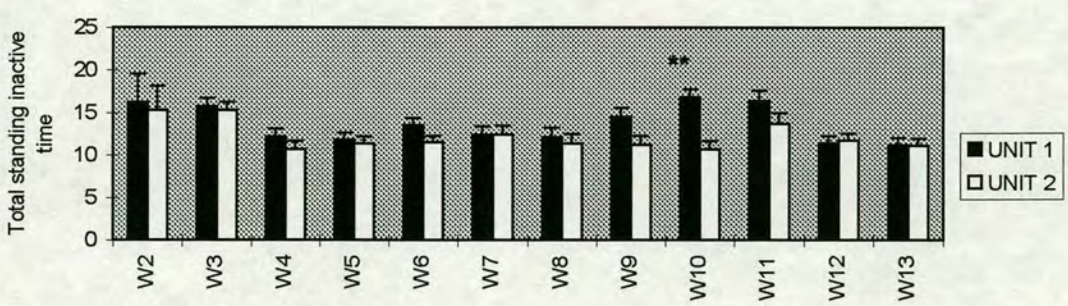


Standing behaviours

Standing inactive

Standing inactive was calculated from the sum of the time standing inactive within the cubicles and in the feed or cubicle passages. Treatment had significant effects on total time spent standing inactive in watch 10 only (Fig 4.24).

Fig 4.24 Comparison of total time standing inactive (% of scans) between treatments



Calving season had the largest effect on total time spent standing inactive within each treatment (Figs 4.25 & 4.26). Unit 1 spring calvers stood for significantly longer in watches 5 and 8 to 11 than autumn calvers on the same treatment. Similarly, unit 2 spring calvers stood inactive for significantly longer in watch 8 only (Fig 4.26).

Fig 4.25 Comparison of total time spent standing inactive (% of scans) between calving season within unit 1

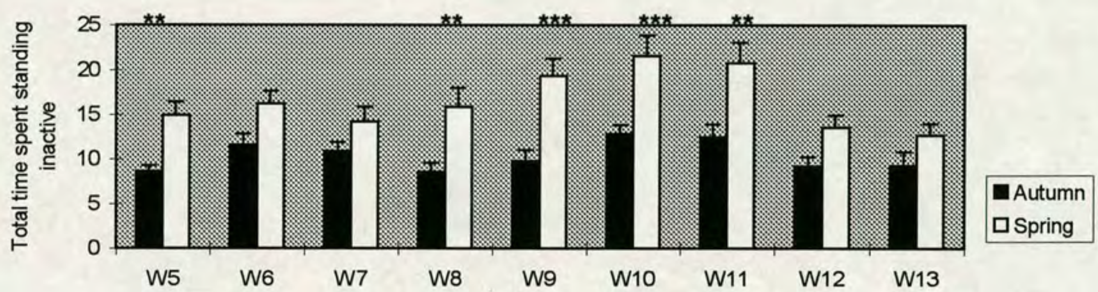
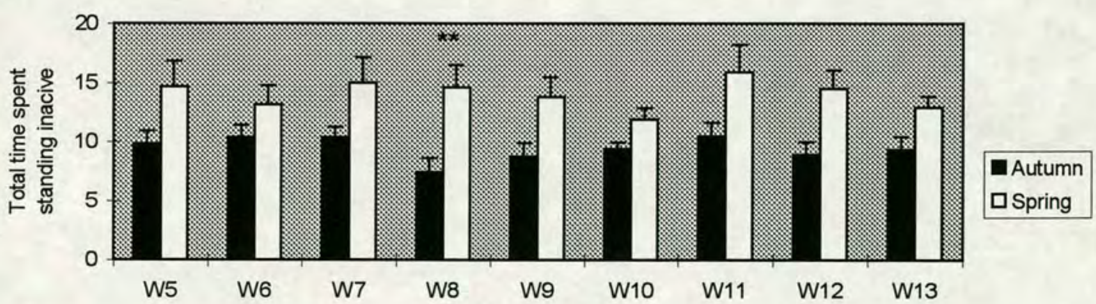


Fig 4.26 Comparison of total time spent standing inactive (% of scans) between calving season within unit 2

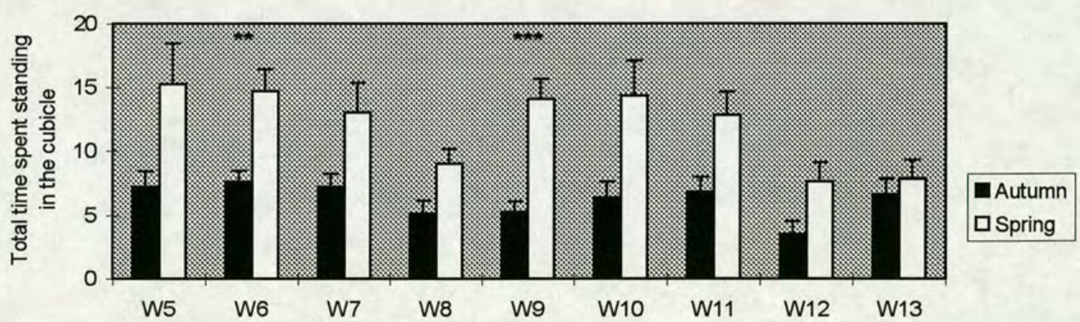


Standing in the cubicles.

Total time spent standing in cubicles was calculated from the sum of standing inactive, standing ruminating and miscellaneous standing behaviours performed within the cubicles. Treatment did not have any effect on total time spent standing in the cubicle in any watch (p>0.01). The overall means were 9.1% (sem 0.7) and 8.4% (sem 0.6) for units 1 and 2 respectively.

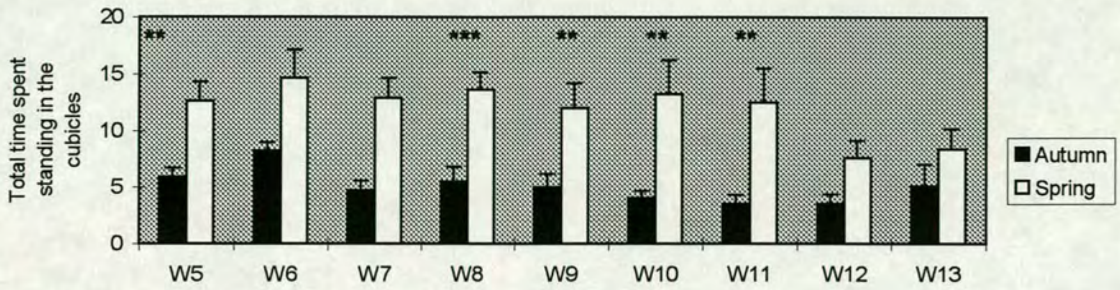
Calving season also had a large effect on time standing in the cubicles. Unit 1 spring calvers stood for significantly longer within cubicles than did autumn calvers in watches 6 and 9 (Fig 4.27). Overall there was a striking difference between calving season, autumn calvers standing for less time within the cubicles (autumn= 6.21%, sem 0.43 vs spring= 12.06%, sem 1.01) however within calving season there were large variations within individuals animals in the spring calving group.

Fig 4.27 Comparison of total time spent standing within the cubicles between calving season in unit 1



Within unit 2 the effect of calving season mirrored that in unit 1. The spring calving animals stood inside the cubicles longest in watches 5, 8 to 11 (Fig 4.28). Similarly to unit 1, the autumn calvers in unit 2 stood within the cubicles for less time (autumn= 4.92%, sem 0.72 vs spring= 8.43%, sem 0.64).

Fig 4.28 Comparison of total time spent standing within the cubicles between calving season within unit 2



4.3.3 Factor analysis of behaviour

To firstly identify behavioural variables that account for large proportions of the variance and exclude variables that have negligible effects on the data, all behavioural variables were used in an initial principal component analysis. The first seven behavioural variables that accounted for the largest proportion of the variance (approx. 85%) were used in the subsequent factor analysis. These selected behaviours are listed below (codes for the behaviours in the loading plots are in brackets)

- Standing inactive in the passageway (**STIN**)
- Standing inactive in the cubicle (**STINC**)
- Standing ruminating in the passageway (**STRM**)
- Standing ruminating in the cubicle (**STRMC**)
- Standing feeding (**STFE**)
- Lying inactive (**LI**)
- Lying ruminating (**LIRM**)

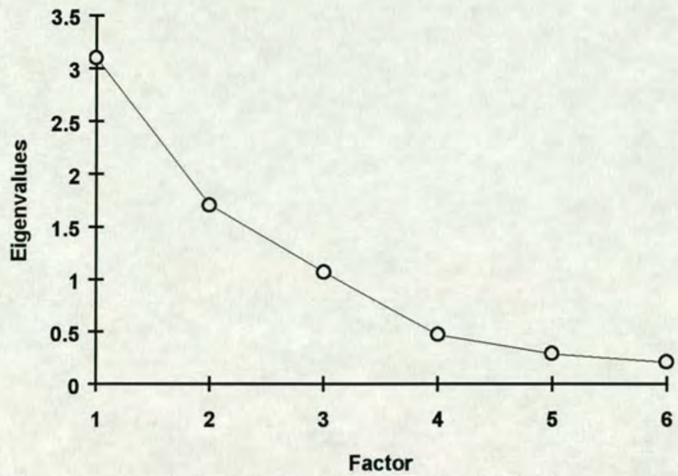
Data from watches 5 to 12 was combined for an overall factor analysis for each treatment and calving season. To see if the relationship between behavioural, variables in each watch was fairly constant, Kendall's test of concordance was performed on each behavioural variable for all animals in the 9 watches in question. This test calculated the Kendall's coefficient of concordance (W) which is an expression of the degree of association between the variables in each watch (Siegel & Castellan, 1988). The pattern of association was consistent for all behavioural variables between all watches (Table 4.1). It was therefore reasonable to perform a factor analysis on calculated means for each behavioural variable for each animal across the 9 watches.

Table 4.1 Association of each behavioural variable over watches 5 to 12

Behavioural variable	W	χ^2	D.F	SIG
Standing inactive in the passageway	0.712	285	8	<0.001
Standing inactive in the cubicle	0.523	235	8	<0.001
Standing ruminating in the passageway	0.698	279	8	<0.001
Standing ruminating in the cubicle	0.655	262	8	<0.001
Standing feeding	0.423	168	8	0.001
Lying inactive	0.416	166	8	0.001
Lying ruminating	0.716	286	8	<0.001

Initially principal factor analysis revealed 3 factors having eigenvalues greater than 1, accounting for 84 % of the variance. The initial scree plot is shown in Fig 4.29.

Fig 4.29 Scree plot of initial 6 factors



Factor loadings are a measure of the association between a behavioural variable and the factor of which it is a component. They range from -1 to 1 where zero would indicate no association. Rotated factor 1 (eigenvalue 3.11), loaded heavily, i.e.$\geq\pm$ 0.5, for standing inactive, standing ruminating in the cubicle and lying ruminating (Table 4.2). This factor was termed **Stand cubicle/lie ruminate.**

Rotated factor 2 (eigenvalue 1.71) was heavily loaded negatively for the behaviours standing inactive and standing ruminating in the passageway and was therefore termed **stand passageway** (Table 4.2).

Rotated factor 3 (eigenvalue 1.07), loaded heavily positive for standing feeding positively and strongly negative for lying inactive (Table 4.2). This factor was termed **feed/lie**.

Table 4.2 Factor loadings for each behaviour measure (bold indicates behaviours with large influence)

Variable	Factor 1	Factor 2	Factor 3
Standing inactive in passageway	0.361	**-0.864**	-0.066
Standing inactive in cubicle	**0.865**	-0.133	-0.244
Standing ruminating in passageway	0.093	**-0.934**	0.134
Standing ruminating in cubicle	**0.903**	-0.113	0.132
Standing feeding	0.361	0.147	**0.901**
Lying inactive	-0.016	0.278	**-0.864**
Lying ruminating	**-0.744**	0.491	-0.092
% Variance accounted for	32	28	24

The relationship between the behaviours can be shown by plotting rotated loadings from factor 1 against factor 2 and factor 1 against factor 3 (Fig 4.30 & Fig 4.31).

Fig 4.30 Factor loadings for each behaviour on factor 1 and 2

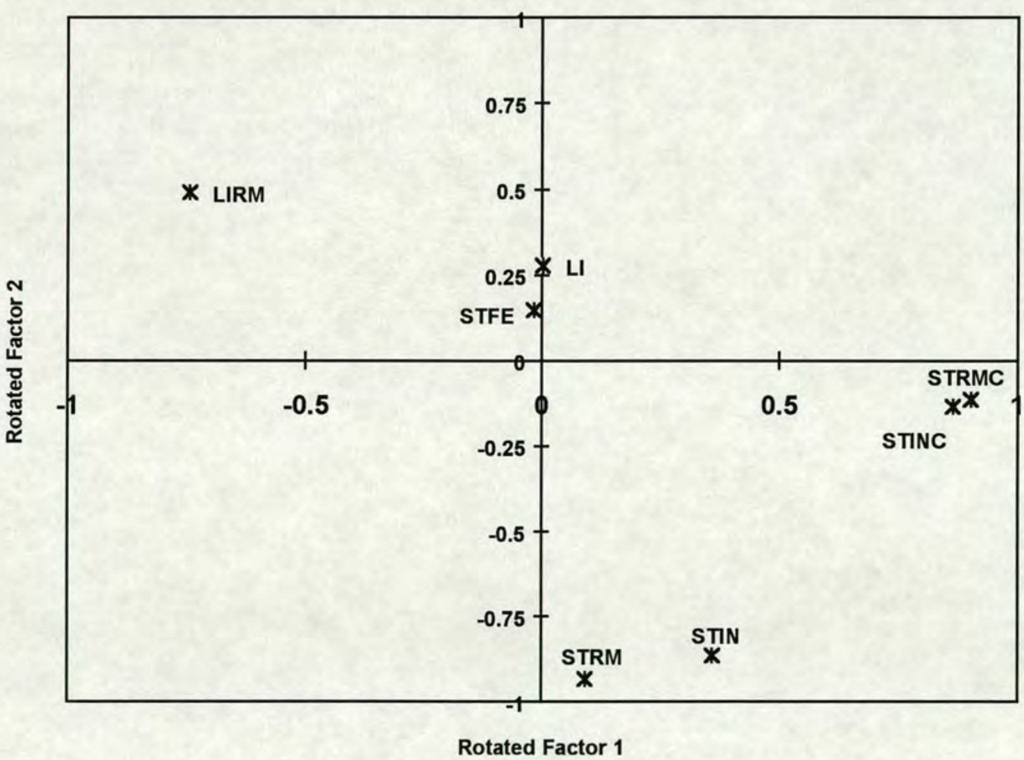


Fig 4.31 Factor loadings for each behaviour on factors 1 and 3

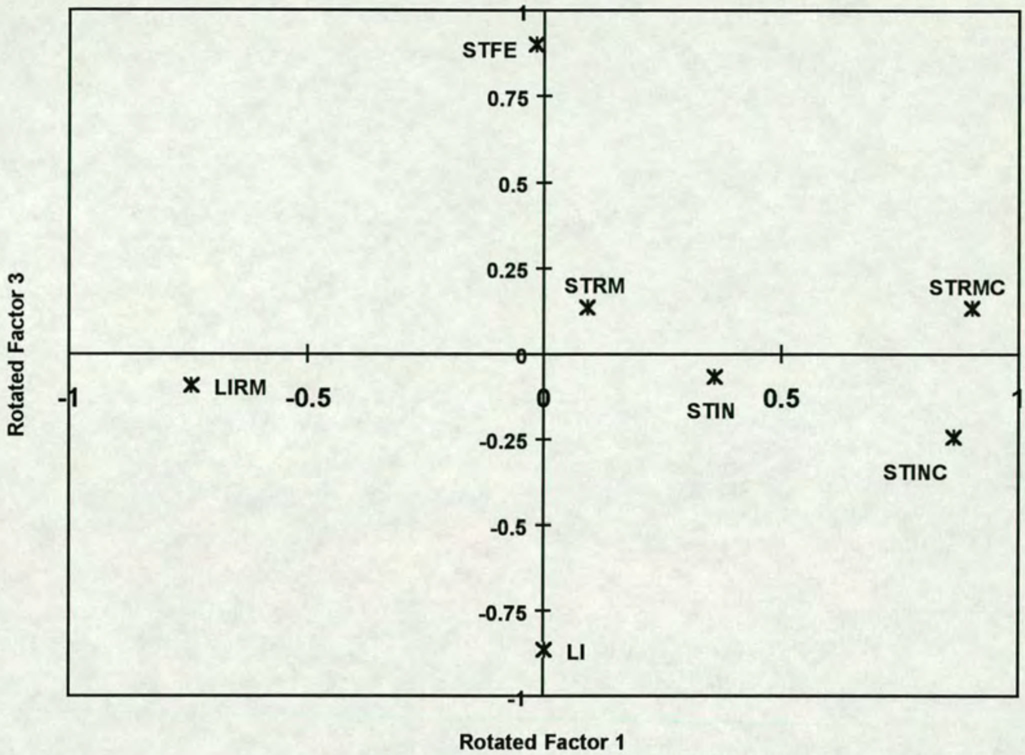


Figure 4.30 shows that the most influential variables for factor 1 i.e. lying ruminating, standing inactive and ruminating in the cubicle are exerting opposing influences on that factor. The plot of factor 1 against 3 (Fig 4.31) shows that standing feeding and lying inactive have the greatest loadings along the factor 3 axis but have opposite loadings which mean that animals that lie for longer feed for less time and vice versa.

Factor scores

The analysis also generated a factor score coefficient which concerns the association between variables and factors. The value on a particular variable for each individual animal was multiplied by the score coefficient to generate a score for that factor. The sum of all the scores for each variable in a given factor provided an overall score for that animal.

The factor scores of each individual animal for the three factors were analysed using a two way GLM ANOVA to investigate the effects of treatment and season on behaviour.

Treatment effects

Treatment had a significant effect on factor 3. This factor was mostly composed of standing feeding and lying inactive. From the previous analysis of treatment effects on behaviour we see that unit 1 would score highly positive on this factor as feeding time has a strong positive factor loading on this variable (Table 4.3).

Table 4.3 Effect of treatment on factor scores for the first 3 factors

	Factor 1 (Stand cubicle/lie ruminate)			Factor 2 (Stand passageway)			Factor 3 (Feed/lie)		
Treatment	Mean	SEM	p	Mean	SEM	p	Mean	SEM	p
Unit 1	0.2	0.20	0.12	-0.14	0.21	0.37	0.346	0.2	**0.003**
Unit 2	-0.2	0.18		0.15	0.16		-0.38	0.16	

Calving Season and parity

Unit 1

Within unit 1, the low input unit, calving season had a significant influence on factor 1 and 3 but not on factor 2. There was no significant difference between heifer and cows for factors 1-3 within unit 1 (Table 4.4).

Table 4.4 Effect of calving season and parity on factor scores within unit 1

	Factor 1			Factor 2			Factor 3		
Season	Mean	SEM	p	Mean	SEM	p	Mean	SEM	p
Autumn	-0.389	0.20	**0.001**	0.277	0.284	0.08	0.798	0.21	**0.016**
Spring	0.750	0.28		-0.519	0.30		-0.074	0.303	
	Factor 1			Factor 2			Factor 3		
parity	Mean	SEM	p	Mean	SEM	p	Mean	SEM	p
Heifer	0.39	0.3	0.09	-0.165	0.24	0.81	0.08	0.17	0.06
Cow	-0.08	0.22		-0.094	0.41		0.73	0.40	

Unit 2

Season had a significant influence on factor 1 only whilst parity influenced factor 3.(Table 4.5).

Table 4.5 Effect of calving season and type on factor scores within unit 2

	Factor 1			Factor 2			Factor 3		
season	Mean	SEM	p	Mean	SEM	p	Mean	SEM	p
Autumn	-0.69	0.16	**0.001**	0.20	0.22	0.8	-0.261	0.17	0.3
Spring	0.478	0.254		0.06	0.27		-0.54	0.32	
	Factor 1			Factor 2			Factor 3		
parity	Mean	SEM	p	Mean	SEM	p	Mean	SEM	p
Heifer	-0.21	0.27	0.4	0.21	0.21	0.7	-0.713	0.18	**0.002**
Cow	-0.234	0.18		0.036	0.27		0.229	0.21	

4.4 Discussion

4.4.1 Treatment effects

Feeding time

During the first year of study, treatment had little effect on feeding time. Feeding time was similar in each unit over the majority of the watches possibly because the production differences between units were not as extreme as in the second year or because the sample size of animals was not sufficient to show any significant effect of treatment.

There was a marked difference in feeding time between treatments in the second year of study. Unit 1, the low dietary input unit, spent a significantly longer time feeding in 5 of the 13 watches, and showed the same trend in all other watches. As unit 1 animals are of high genetic merit (high ITEM) they were predisposed to produce a high yield and were probably highly motivated to feed to meet metabolic demand. As the dietary ration on this treatment was fibrous and bulky, it increased processing time, requiring the animals to feed for a prolonged period (Jackson *et al*, 1991; Phillips, 1993). Although the proximate values for the mix composition indicate that NDF intake was higher for Unit 2, it does not give any information on the quality of the fibre. For Unit 2 a large proportion of the NDF was obtained from the grainbeet component of the complete mix ration which would be considerably easier to digest and handle compared to NDF from forage. The contrast in feeding time between treatments was most evident in watches 12 and 13, a period which coincided with the greatest amount of estimated dietary straw dilution within unit 1.

Lying behaviour

There was no significant difference in total time spent lying between treatments in year 1. Lying times ranged between 40 and 55% of all scans. These observations are consistent with other studies which measured the lying behaviour of cubicle housed cows (Metz & Wierenga, 1987; Singh *et al* 1993a, 1994) and are comparable to the total lying times recorded on pasture in the same herds (personal observation).

In year 2 lying time showed distinct treatment differences; overall, unit 2 animals lay for longer in most watches but significantly so in 4 out of 13 watches. The differences seen in watches 3 to 5 were the result of a fall in lying time post-calving for autumn calving animals in unit 1. Some studies have shown that lying time falls dramatically post-calving as animals approach peak lactation (Ruckebusch, 1975). This suggests that these animals were sacrificing lying time to meet energy demand to feed, a behaviour enhanced by the fact that they were feeding on a low energy ration.

The lying inactive component of the total lying time followed a similar pattern to overall lying time in that unit 1 animals spent less time lying inactive in the early watches which again coincided with the calving of autumn season animals and their apparent need to prioritise metabolic demand above lying time.

Lying ruminating showed additional differences between treatments. Unit 1 animals lay and ruminated for significantly less time in watches 2 and 5 for the reasons stated above. However unit 1 animals lying ruminating time also fell in watches 9 to

11. This roughly coincided with the 2-6 week post-calving period of the spring calving animals and may have represented an attempt by the spring calving animals to maximise feeding time by sacrificing lying time. Furthermore there was no significant difference in total rumination time. Although not recorded, a certain proportion of the lying inactive time would have been spent awake. This could possibly be considered a "luxury" component to lying and is probably the most readily sacrificed component in terms of activity budgets.

Rumination

No difference in overall ruminating behaviour between treatments was apparent. Ruminating times were extremely similar between units ranging between 28-35 % of scans. One could speculate from the pattern of total rumination time over the housing period that the expression of this particular behaviour was consistent between watches. This suggests that although unit 2 received more silage and unit 1 more straw in their respective rations, the fibre ingested took comparable amounts of time to process by rumination and digest within the rumen.

Behaviour while standing

Treatment had no effect on standing and ruminative behaviour within cubicles. The total time spent standing inactive was significantly higher in unit 1 in watch 10 only. This period coincided with the approach to or achievement of peak yield for the spring calving group, and the increased standing was possibly associated with the feeding time which was increasing over this period.

4.4.2 Calving season effects on behaviour (Year 2 only)

Feeding behaviour

Within unit 2, feeding behaviour was not significantly affected by calving season, except in one watch, indicating that both spring and autumn calving animals were able to meet energy demand on the provided ration.

Major differences were seen within unit 1, probably resulting from the partial substitution of silage with increasing amounts of straw. Autumn calvers were feeding for longer in watches 5 and 7 because they were fed a larger ration compared to spring calvers. In contrast, the differences in watches 9 and 10, a period when most of the spring calvers had entered the milking herd were probably linked to the yield differences between the calving groups.

Behaviour whilst standing

Time spent standing inactive showed very similar responses in each unit with the spring calvers spending a significantly larger proportion of their daily activity engaged in standing doing nothing. This difference was more convincing within unit 1 but the trend was also apparent for unit 2. A possible reason for this is that the spring calvers were kept in a separate group prior to calving, usually with less than 20 other cows. This group's lying and feeding space consists of a separately penned area of the cubicle house; in some instances access to the feed passage was negotiable via one entrance only compared with 3 in the case of the milking animals. Within such a situation there was a smaller walking area for animals which caused congestion or left the spring calvers unwilling to go and feed because of the possible risk posed by an encounter with a dominant or aggressive individual

(Potter & Broom, 1987; Colam-Ainsworth *et al*, 1989). Animals may have adopted an idling strategy to decrease the degree of confrontation with other herdmembers. Post-calving, after entry to the milking herd this type of "idling" strategy might persist as encounters with dominant animals would be more numerous and such encounters may have served to reinforce the idling strategy.

The total time spent standing within the cubicle showed that spring calvers spent a significantly longer time in the cubicles, in most cases double that of autumn calvers. The expression of standing within the cubicle may indicate it is another non-confrontational coping strategy. Autumn calving animals were kept within a larger group and had a longer adaptation period in terms of establishing their rank in the social hierarchy during housing than spring calvers. In addition the dynamics of the spring calving/dry cow group compared to the milking herd were more changeable as the size of the groups was very different. Animals were regularly dried off and transferred from the milking herd into the spring calving/dry cow group which possibly caused disruption as hierarchies did not properly establish. In such a situation, heifers and second lactation cows may have adopted the idling/standing motionless strategy as the opportunity of winning an agonistic confrontation against an older individual is small and as there is little space to engage in escape behaviour the risk of injury is increased.

Ruminative Behaviour

Both units showed similar significant trends, in that the spring calvers ruminated for longer in all watches but significantly longer in 2 out of 13 watches. Rumination may be a necessary maintenance behaviour but extended rumination times showed by spring calvers must certainly have an explanation. If standing ruminating (both inside and out of the cubicles) is examined within each unit, we see that spring calvers spent an increased proportion of their time engaged in ruminatory behaviour whilst standing. If the spring calving animals were standing motionless for longer both out and inside cubicles as a non-confrontational coping strategy as mentioned above, then they may engage in rumination during this period of idling.

4.4.3 Factor analysis

Initial factor analysis showed that there were 3 principal factors in which the 7 most common behaviours have most influence. These factors accounted for 84% of the total variance. Factors 4 and above which had eigenvalues of less than 1 were ignored since they could have been generated by random variance.

Factor 1

Behaviours which have a high loading in factor 1 were essentially various ruminative and standing behaviours. The loading for standing inactive and standing ruminating in the cubicle had an opposite loading to lying ruminating. This shows that there is a negative relationship between these 3 behaviours. The relationship suggests that animals which engaged in the most ruminative behaviour whilst lying were less likely to stand and ruminate in the cubicle. An analysis of treatment and calving season effects showed that treatment had no significant effect on factor 1, but within each treatment, calving season effects were very strong. Spring calving animals factor scores were positive whilst those of autumn calvers were negative. This showed that there was a significant tendency for autumn calvers to engage in more ruminative behaviour whilst lying and less whilst standing within the cubicles. This may be because spring calvers had more time to engage is such standing behaviours or that autumn calvers prioritise lying ruminating above standing ruminating. These findings also suggest the existence of a non-confrontational coping strategy of increased standing in the cubicles performed by spring calvers.

Factor 2

The major behaviours which had significant loadings on factor 2 were standing inactive in the passageway and ruminating in the passageway and appeared to be closely related. This is possible considering that an animal may ruminate if she is in a relatively undisturbed location whilst idling. Another explanation is that the times an animal was observed idling it was merely pausing during its ruminative behaviour given that the amount of time spent recording an individual animal's behaviour during a scan is short e.g. a few seconds. Neither treatment nor calving season had any significant effect on this factor.

Factor 3

Factor 3 accounted for 24% of the total variance between factors. Lying inactive and feeding were the behaviours that had the greatest loadings for this factor but there was a negative relationship between them - defined by the sign (see loading plot). This means that animals which fed for longer had a lowered lying time as animals possibly sacrificed their time spent lying inactive to feeding to meet metabolic demand.

Treatment had a highly significant effect on factor 3: mean factor scores for unit 1 indicate that they either fed for longer or lay for less time than unit 2. This could be considered to be the major effect of manipulating production in this system.

Within unit 1 calving season had a significant effect on factor three. Autumn calvers appear, from the mean factor score to have either fed for longer and lay for less time or both relative to spring calvers. Within unit 2, the effect of parity (heifer or cow) was significant on factor 3, in that cows appear to have fed for longer and lay for less time than heifers. This is supported by the observation of Colam-Ainsworth *et al* (1989) indicating that heifers show an abnormally reduced lying time.

The spring calvers spent a longer time standing within each unit, possibly due to a management effect as the timing of housing and grouping of these animals differ relative to the autumn calvers. The main differences in behaviour between treatments were altered feeding and lying times in the second year. The physical "bulkiness" diet fed to unit 1 due to its straw content increased feeding time for this herd. Animals on this diet although capable of producing high yields if fed an adequate high energy diet were required to "cope" on a lower energy diet; they appeared to be increasing feeding time at the expense of lying time to maximise energy intake. In terms of nutrition and management these herds represented fairly extreme regimes in the range of those that are possible in the current Scottish situation. Therefore care must be taken in systems relying predominantly on forage with little or no concentrate, to ensure lying time does not fall to levels which may increase the risk of lameness and hence reduce a lactating cow's welfare.

5 Influence of production and management on the development of claw lesions and other hoof parameters

5.1 Introduction

Lesion development in dairy cattle is affected by the calving and housing period. There is a rise in prevalence of lesions after entry to housing but a much larger response occurs 2-3 months after calving. The level of lameness in the herd is relatively easy to measure but as not all animals become lame, it would therefore be advantageous to obtain some other method of assessing damage attributed to risk factor challenge to the claws of cows. Subclinical lesions in the claws are direct precursors to clinical lesions (Greenough & Vermunt, 1991) and as such are important in determining the relationship between external factors and the incidence of lameness in defined conditions.

The relationship between diet, calving season and lesion expression is investigated here. Diet has been implicated in the development of lesions, especially at the extremes of protein or concentrate supplementation (Bazeley & Pinsent, 1984; Livesey & Fleming, 1984; Manson & Leaver, 1988a). Acids produced by fermentation of starchy concentrate dramatically alters rumen conditions, causing rumen microfauna to die, resulting in the release of large amounts of endotoxins into the blood; it is believed that these endotoxins are directly linked to the initiation of laminitic disease (Kelly & Leaver, 1990; Vermunt & Greenough, 1994). One study reported that supplementation of a methionine analogue in cow diets resulted in faster growing but softer claw horn, and a possible reduction in disulphide bonds in the keratin secondary structure (Clark & Rakes, 1982). However in a later study when a more commercial high sulphur protein concentrate based on meat and bonemeal was compared with a soya based concentrate, no difference in terms of lesion and hoof hardness was found between animals fed these diets (Offer *et al*, 1997).

Calving is another factor implicated in the development and appearance of lesions (Greenough & Vermunt, 1991). From the previous chapter, autumn and spring calvers show different locomotion scores indicating that there may be a difference in the expression of lesions as the former would be exposed to the additive risk of the closely coinciding calving and housing stresses.

The present study aimed to assess the effect of 2 differing management and nutritional regimes on the development of subclinical lesions in the claws of first and second parity cows. The secondary effect of calving season could also be investigated in parallel within the treatment effect. Assessment of lesions using a measurable scale provided an indication of the extent and severity of the disease affliction of any particular claw (Logue *et al*, 1994; Bradley *et al*, 1989; Leach *et al*, 1997). Examinations were carried out from before calving until well after the period of peak subclinical lesion incidence, expected 2-3 months after calving based on previous studies (Dewes, 1978; Rowlands *et al*, 1983).

Alongside lesion data, it was also valuable to collect data for other hoof parameters such as hoof angle, length and hardness which may change in relation to calving and housing. Hoof angle is particularly important as it is linked to the risk of developing lameness (Manson & Leaver, 1988a) being indicative of adequate weight distribution in the claw. Similarly, hardness of the claw which represents a possible measure of the hoof's ability to withstand mechanical stresses may change in response to diet or as a result of exposure to risk factors during the housing and calving period. The measurement of growth and wear complemented that of hardness and served as an important indication of the extent of the environmental effect on the claws. The differences in these measures in relation to the calving period were again investigated from before until well after calving.

5.2 Materials and methods

All 1st and 2nd parity animals from each unit were used in this study for further details see section 4.2.1. All feet were examined in relation to the calving and housing period and followed through 1 complete housing period from September '95 to April '96.

5.2.1 Animals and housing

Fifty six animals roughly divided between treatments were used - these are described fully in section 2.2.2 as group II. Within unit 1, the low concentrate input herd, experimental animals consisted of 17 heifers (9 autumn calving, 8 spring) and 11 second lactation cows (5 autumn, 6 spring). Animals on unit 2, the high concentrate input herd, comprised 18 heifers (10 autumn calving, 8 spring) and 10 second lactation cows (5 autumn, 5 spring).

Animals were housed in a conventional cubicle house with a double row of Newton Rigg cubicles and a solid floor feeding passage with individual feed spaces. For further details see section 2.2.3.

5.2.2 Hoof examination procedure

All feet were examined at regular intervals before and after calving. They were scored for interdigital disease, heel erosion and subclinical lesions on defined scales. A complete description of the analysis can be found in section 2.8.

5.2.3 Timing of measurements

Problems were encountered in the timing of the examination periods relative to calving, since for practical reasons examinations were made roughly every 14 days. The data was simplified by defining 6 examination periods as shown below (Table 5.1).

Table 5.1 Grouping of the hoof examination periods (for both autumn and spring calvers)

Examination period	Weeks post-calving	Mean	sem
1	-16 to -10	-13.5	0.6
2	-7 to -3	-5.7	0.4
3	-1 to 1	0.2	0.1
4	6 to 9	7.2	0.9
5	15 to 20	17.6	1.53
6	22 to 28	26.1	1.9

5.2.4 Statistical analysis

This study suffers from problems associated with the analysis of treatment and calving season effects. These two factors are largely confounded in the analysis, partly due to the lack of synchronous calving in the spring calving animals and partly due to the lack of replication between years.

Hoof measures were compared between treatments using general linear model ANOVA. Within each treatment the effect of calving season and parity were compared using the same test. Each examination period was analysed separately and weeks post-calving included as a covariate. Due to the numerous tests being performed on the same data set, the level of significance was raised to 1% in order to reduce the likelihood of a spurious significant result.

Differences in hoof measurements over time were analysed using repeated measures ANOVA. This takes into account previous observations are not independent of subsequent observations when analysing the variance structure. Thus the effect of treatment and other factors (unit, calving season and parity) are analysed together with the underlying factor of time or examination period in this case. The examination period is analysed as a sub plot within the factor model main plot. Differences in lesion, heel erosion and infectious disease scores between periods were analysed using a Wilcoxon signed rank test. In this test the median lesion score difference between average precalving scores and scores later into lactation were compared with a median of zero i.e. no difference between pre calving scores and later scores. The test in this case is used as an indicator of the significance of increases or decreases in lesion scores in specific examinations. It was considered unnecessary to compare all postcalving examinations with the precalving lesion scores as the test only serves as an indicator of changes over time. For this reason only the immediate postcalving (examination 3) and mid lactation (examination 5) are compared to the precalving scores.

The lesion, heel erosion and dermatitis scores were analysed non-parametrically using Kruskal-Wallis ranked procedures for any treatment and calving season effects. Due to the same test being performed repeatedly on the same data set the level of significance was increased to 1%.

5.3 Results

5.3.1 Hoof measures

Weeks post-calving had no significant covariate effect within any of the Examination periods on any of the following hoof measures ($p>0.01$).

Hoof Angle

Treatment had no significant effect on the hoof angle of either the outer or inner hind claws, ($p>0.01$, see appendix). The outer claws were always steeper than the inner claws.

Hoof angle differed significantly over time across all animals ($p<0.01$). The outer claw angle during the first 2 examinations was shallower than during the final 2 examinations, and the claw appeared to change in angle from examination 3 (i.e. parturition) onward (Table 5.2). A similar change was recorded in the inner claw angle but in contrast to the outer claw there was a more gradual change in claw angle through each examination (Table 5.2).

Table 5.2 Comparison of the angle of the outer and inner claws between examinations with data from the two treatments combined

Examination period	Mean weeks post-calving	Angle of outer claw (deg.)	sem	Angle of inner claw (deg.)	sem
1	-14	48.8	0.6	46.5	0.4
2	-6	48.7	0.9	47.5	0.9
3	0.2	50.5	0.6	47.2	0.5
4	7	52.8	0.6	48.9	0.6
5	18	51.5	0.4	48.3	0.5
6	26	52.5	0.6	49.7	0.6

Within unit 1 there were significant effects of calving season in watches 3 and 5. In watch 3, spring calvers had significantly steeper inner claw angles ($p<0.01$), furthermore the outer claw also showed this strong trend (Table 5.3). Autumn calvers had significantly steeper outer claws during examination period 5 only ($p<0.01$).

Table 5.3 Effect of calving season on the claw angle within unit 1

		Angle of outer claw			Angle of inner claw		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	49.1	49.2	0.39	46.2	47.0	0.15
		(1.2)	(1.3)		(0.9)	(0.8)	
2	-6	47.5	52.9	0.02	**44.8**	**51.6**	**0.004**
		(1.15)	(1.7)		(1.1)	(1.7)	
3	0.2	49.5	52.7	0.05	46.0	49.8	0.032
		(1.14)	(1.0)		(0.9)	(0.9)	
4	7	52.1	52.2	0.94	48.3	49.7	0.51
		(1.14)	(1.9)		(0.9)	(1.8)	
5	18	**52.6**	**49.1**	**0.002**	48.5	48.5	0.92
		(0.39)	(0.6)		(0.8)	(0.9)	
6	26	51.5	52.0	0.74	48.6	50.50	0.71
		(0.70)	(0.9)		(0.7)	(1.9)	

(Standard errors are shown in brackets)

There were no significant differences over time for the angle of the outer or inner claws in unit 1 ($p>0.01$). However hoof angle was always shallowest in the first precalving period (Table 5.4).

Table 5.4 Comparison of hoof angles between examinations within unit 1

Examination period	mean weeks post-calving	Angle of outer claw	sem	Angle of inner claw	sem
1	-14	49.1	0.9	46.6	0.6
2	-6	50.4	1.2	48.1	1.3
3	0.2	51.0	0.8	47.7	0.8
4	7	52.1	1.0	48.8	0.9
5	18	51.4	0.5	48.5	0.6
6	26	51.6	1.0	48.9	0.8

Within unit 2, spring calvers had significantly steeper claws (both inner and outer) in examination 2, in addition, inner claws were also significantly steeper in examination 4. Autumn calvers had significantly steeper outer claws in examination 5 (Table 5.5).

Table 5.5 Effect of calving season on the claw angle within unit 2

		Angle of outer claw			Angle of inner claw		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	46.8 (1.4)	49.5 (1.0)	0.21	45.83 (1.2)	47.11 (0.5)	0.90
2	-6	**44.5** (0.6)	**49.8** (2.2)	**0.005**	**44.1** (0.5)	**49.7** (2.0)	**0.006**
3	0.2	48.4 (1.0)	52.1 (1.6)	0.07	46.0 (0.6)	48.0 (1.4)	0.354
4	7	52.8 (0.61)	55.6 (1.7)	0.04	**48.1** (0.7)	**51.0** (1.2)	**0.007**
5	18	**53.0** (0.76)	**49.7** (1.1)	**0.003**	49.4 (0.9)	46.2 (1.4)	0.06
6	26	53.7 (1.1)	51.3 (0.6)	0.17	50.6 (1.2)	49.5 (0.9)	0.29

(Standard errors are shown in brackets)

There was no difference in claw angle between heifers or cows within either unit ($p>0.01$). Weeks post-calving had no significant covariate effect ($p>0.01$). There were significant differences in the angle of the outer claw over time ($p<0.01$). Outer claws were shallower in the first 3 examinations than in examinations 4 and 6 (Table 5.6).

Table 5.6 Comparison of hoof angle between examinations within unit 2

Examination period	mean weeks post-calving	Angle of outer claw	sem	Angle of inner claw	sem
1	-14	48.3	1.0	46.3	0.6
2	-6	47.1	1.2	46.7	1.2
3	0.2	49.9	0.9	46.8	0.7
4	7	53.8	0.7	49.0	0.7
5	18	51.6	0.7	48.1	0.9
6	26	53.0	0.8	50.3	0.9

Claw length

Treatment had no significant effect on claw length across all examinations ($p>0.1$, see appendix). Although claw length appeared to decrease over time this was not significant ($p>0.05$).

Spring calvers had significantly longer outer claws in examination 5 (Table 5.7). Calving season had no significant effect upon inner claw length ($p>0.01$).

Table 5.7 Effect of calving season on the length of claws within unit 1

		Length of outer claw (mm)			Length of inner claw (mm)		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	76.6 (1.4)	82.1 (1.9)	0.10	76.7 (1.2)	80.7 (1.6)	0.18
2	-6	79.9 (0.8)	77.0 (1.4)	0.39	79.3 (0.9)	76.3 (1.5)	0.42
3	0.2	78.4 (0.6)	76.4 (1.3)	0.03	78.5 (0.6)	77.1 (1.4)	0.08
4	7	77.2 (0.8)	75.6 (1.4)	0.20	77.0 (0.9)	75.4 (1.3)	0.27
5	18	**75.2** (0.9)	**80.8** (1.1)	**0.007**	75.7 (0.9)	77.6 (0.9)	0.15
6	26	76.6 (1.1)	82.0 (2.0)	0.09	75.4 (0.9)	80.5 (0.5)	0.08

(Standard errors are shown in brackets)

Within unit 1 there were no significant differences over time in terms of claw length ($p>0.1$).

Due to insufficient numbers of cows in examinations 1, 2, and 6 the effect of parity on claw length was only analysed in examination 3, 4 and 5. The length of the outer claw was not significantly different between cows and heifers in these examinations ($p>0.1$).

Unit 2 autumn calvers had significantly longer outer and inner claws during examination 4 (approx. 7 weeks post-calving). In addition autumn calvers had significantly longer inner claws during examination 3 (Table 5.8).

Table 5.8 Effect of calving season on the length of claws within unit 2

		Length of outer claw (mm)			Length of inner claw (mm)		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	76.7 (1.4)	78.4 (1.6)	0.67	78.1 (0.8)	76.1 (1.9)	0.80
2	-6	79.0 (1.5)	79.2 (1.9)	0.31	77.7 (0.9)	78.3 (1.5)	0.33
3	0.2	79.7 (1.3)	76.2 (1.5)	0.09	**78.9** (1.1)	**74.8** (1.7)	**0.01**
4	7	**77.9** (1.2)	**74.6** (0.4)	**0.003**	**77.5** (1.1)	**73.4** (0.9)	**0.006**
5	18	77.1 (1.5)	78.0 (2.1)	0.67	76.1 (1.4)	76.3 (1.9)	0.97
6	26	78.9 (1.3)	78.5 (1.7)	0.31	77.8 (0.9)	64.8 (10.3)	0.20

(Standard errors are shown in brackets)

As with unit 1 there were enough comparative numbers to perform analysis of parity effects in exams 3, 4 and 5. The outer claws were significantly longer in cows compared to heifers in examinations 3 and 5 ($p \leq 0.01$; 76.5 sem=0.9 vs 81.1sem=1.9; 75.0 sem=1.2 vs 82.0 sem=1.7). The inner claws were significantly longer in cows than in heifers during examinations 3 and 5 ($p \leq 0.01$; 74.8mm sem=0.9 vs 81.1mm sem=1.5; 74.2mm sem=1.1 vs 80.4mm sem= 1.7).

Growth and Wear

The effect of treatment on overall growth and wear together with net growth (i.e. growth minus wear) is shown in Table 5.9. Overall growth did not differ significantly between treatments; however there seemed to be a trend for unit 2 animals' hooves wearing less in examination 2 and more in examination 3 compared to unit 1 animals. (Table 5.9).

Table 5.9 Comparison of claw growth, wear and net growth between treatments

		Growth (mm)			Wear (mm)		
Examination period	mean weeks post-calving	Unit 1	Unit 2	p	Unit 1	Unit 2	p
1	-14	4.2 (0.4)	4.3 (0.5)	0.47	4.1 (0.6)	3.7 (0.7)	0.89
2	-6	5.5 (0.3)	4.8 (0.4)	0.15	6.3 (0.8)	4.2 (0.5)	0.04
3	0.2	5.1 (0.5)	4.6 (0.4)	0.49	5.1 (0.4)	6.3 (0.4)	0.02
4	7	5.4 (0.5)	4.4 (0.7)	0.65	5.6 (0.4)	6.1 (0.4)	0.61
5	18	4.9 (0.4)	5.3 (0.4)	0.97	5.3 (0.4)	5.4 (0.4)	0.98
6	26	4.9 (0.4)	5.7 (0.4)	0.31	4.9 (0.4)	4.7 (0.3)	0.59
		Net growth (mm)					
1	-14	0.1 (0.5)	0.7 (0.6)	0.36			
2	-6	-0.8 (0.7)	0.6 (0.5)	0.16			
3	0.2	0.0 (0.5)	-1.7 (0.5)	0.03			
4	7	-0.2 (0.3)	-1.6 (0.8)	0.33			
5	18	-0.3 (0.4)	-0.03 (0.3)	0.92			
6	26	0.08 (0.3)	1.0 (0.3)	0.14			

(standard errors are shown in brackets)

There were significant differences in hoof erosion over time ($p<0.01$), with less wear occuring in the initial examination period compared to any other examination. Conversely examinations 3 and 4 had the highest wear (Table 5.10). Neither growth nor net growth differed significantly over time.

Table 5.10 Comparison of growth, wear and net growth between examination periods

		Growth		Wear		Net growth	
Exam	Mean weeks post-calving	Mean	sem	Mean	sem	Mean	sem
1	-14	4.2	0.3	3.9	0.4	0.3	0.4
2	-6	5.2	0.3	5.2	0.5	-0.1	0.5
3	0.2	4.9	0.3	5.7	0.3	-0.8	0.4
4	7	5.0	0.4	5.8	0.3	-0.8	0.4
5	18	5.2	0.3	5.3	0.3	-0.2	0.3
6	26	5.4	0.3	4.8	0.2	0.6	0.3

Within unit 1 there were significant differences between autumn and spring calvers in terms of wear and net growth. Autumn calvers had significantly less wear in examination period 2 but significantly more during examination 5. This affects the subsequent net growth values, which were significantly higher for autumn calvers during examination period 2 (Table 5.11). There was no significant difference for growth, wear or net growth between examination periods ($p>0.01$), (Table 5.11) for animals in unit 1.

Table 5.11 Comparison of growth, wear and net growth between autumn and spring calving animals within unit 1

		Growth (mm)			Wear (mm)		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	4.2 (0.1)	4.2 (0.6)	0.90	4.5 (1.9)	4.0 (0.6)	0.85
2	-6	5.6 (0.5)	5.5 (0.4)	0.99	**4.2** (0.9)	**8.2** (0.8)	**0.004**
3	0.2	4.6 (0.4)	5.7 (0.9)	0.08	4.4 (0.4)	6.1 (0.7)	0.03
4	7	5.3 (0.5)	5.5 (0.9)	0.89	5.3 (0.5)	6.1 (0.6)	0.38
5	18	4.9 (0.5)	5.0 (0.4)	0.14	**5.7** (0.6)	**4.3** (0.3)	**0.001**
6	26	4.9 (0.5)	5.5 (0.6)	0.97	4.9 (0.4)	4.9 (0.6)	0.46
		Net growth (mm)					
1	-14	-0.33 (1.8)	0.21 (0.4)	0.80			
2	-6	**1.4** (0.8)	**-2.6** (0.7)	**0.002**			
3	0.2	0.27 (0.7)	-0.39 (0.8)	0.74			
4	7	0.03 (0.5)	-0.57 (0.3)	0.43			
5	18	-0.80 (0.5)	0.68 (0.2)	0.04			
6	26	0.0 (0.3)	0.6 (0.1)	0.38			

(standard errors are shown in brackets)

Growth, wear and net growth did not differ significantly between heifers and cows (P>0.05).

Unit 2, spring calvers had significantly higher overall growth than autumn calvers during examination period 4; however there was no significant difference between calving seasons in terms of hoof wear (Table 5.12). Net growth differed significantly between calving seasons in examination period 4, spring calvers having significantly higher net growth (Table 5.12). There was no significant difference in growth, wear or net growth over time across all animals in unit 2 (p>0.05).

Table 5.12 Comparison of growth, wear and net growth between calving season within unit 2

		Growth (mm)			Wear (mm)		
Examination period	mean weeks post-calving	Autumn	Spring	p	Autumn	Spring	p
1	-14	4.3 (0.6)	4.8 (0.6)	0.19	2.7 (1.0)	4.5 (0.7)	0.27
2	-6	5.4 (0.3)	4.1 (0.6)	0.20	3.8 (0.6)	4.6 (0.9)	0.16
3	0.2	4.8 (0.5)	4.4 (0.6)	0.82	6.1 (0.4)	6.8 (0.6)	0.13
4	7	**2.8** (0.7)	**7.3** (0.7)	**0.002**	6.0 (0.5)	6.2 (0.7)	0.62
5	18	5.9 (0.6)	4.6 (0.3)	0.14	5.7 (0.6)	4.9 (0.2)	0.13
6	26	5.4 (0.4)	6.3 (0.5)	0.89	4.8 (0.4)	4.5 (0.3)	0.06
		Net growth (mm)					
1	-14	1.6 (0.6)	0.3 (0.7)	0.84			
2	-6	1.6 (0.6)	-0.5 (0.7)	0.02			
3	0.2	-1.3 (0.5)	-2.4 (1.1)	0.29			
4	7	**-3.2** (0.9)	**1.0** (0.6)	**0.001**			
5	18	0.2 (0.4)	-0.3 (0.4)	0.46			
6	26	0.6 (0.4)	1.8 (0.6)	0.16			

(standard errors are shown in brackets)

Hoof hardness

Hoof hardness was measured at 5 sites (see chapter 2 fig 2.3). Treatment had no significant effect on hoof hardness (Table 5.13).

Table 5.13 Comparison of hoof hardness (in shore A units) between treatment in each examination

Site	Bulb			1			2		
Exam	Unit 1	Unit 2	p	Unit 1	Unit 2	p	Unit 1	Unit 2	p
1	66.4 (0.8)	66.7 (1.2)	0.06	79.5 (4.75)	83.5 (1.5)	0.79	85.4 (0.8)	81.6 (5.5)	0.38
2	63.2 (1.0)	63.1 (1.2)	0.93	82.3 (0.7)	84.4 (0.9)	0.15	85.7 (0.8)	83.2 (5.3)	0.58
3	55.6 (4.3)	55.8 (4.5)	0.87	72.6 (5.5)	70.7 (5.6)	0.92	76.2 (5.8)	75.5 (6.0)	0.94
4	61.9 (0.7)	58.3 (1.0)	0.02	80.6 (0.6)	80.7 (0.7)	0.74	85.0 (0.7)	83.7 1.8)	0.27
5	57.5 (2.6)	58.7 (0.8)	0.30	76.1 (3.5)	91.0 (10.9)	0.54	80.7 (3.4)	84.4 (0.7)	0.23
6	58.8 (4.2)	60.6 (1.0)	0.99	80.6 (0.6)	81.2 (0.9)	0.95	84.6 (0.9)	86.5 (0.7)	0.02
site	3			wall					
1	88.0 (0.5)	90.6 (1.0)	0.12	98.3 (0.2)	98.3 (0.4)	0.74			
2	88.6 (0.8)	89.9 (0.8)	0.27	98.5 (0.2)	98.2 (0.2)	0.15			
3	76.9 (5.9)	77.2 (6.1)	0.88	86.3 (6.5)	85.8 (6.8)	0.98			
4	88.4 (0.6)	88.6 (0.7)	0.99	98.0 (0.2)	97.9 (0.2)	0.95			
5	84.6 (3.6)	86.9 (0.7)	0.55	93.8 (3.9)	97.9 (0.1)	0.80			
6	87.9 (0.7)	89.0 (0.6)	0.40	98.0 (0.2)	98.0 (0.4)	0.39			

(standard errors are shown in brackets)

Hoof hardness was significantly different over time at sites bulb, 3, and wall across all animals ($p<0.01$, Table 5.14). At the bulb, heel horn was harder during examinations 1 and 2 than at examination 3. At sites 3 (at the toe) and at the wall, hoof horn was softer at examination 3 than at examinations 1, 2, 4 and 6 (Table 5.14).

Table 5.14 Changes in hoof hardness (in shore A units) between examinations in all sites

	Site	Bulb		1		2		3		Wall	
Exam	Weeks post-calving	Mean	sem	Mean	sem	Mean	sem	Mean	sem	Mean	sem
1	-14	65.4	0.7	81.4	2.6	83.6	2.6	89.2	0.6	98.3	0.2
2	-6	63.2	0.8	83.3	2.6	84.5	2.6	89.2	0.6	98.4	0.1
3	0.2	55.6	3.1	71.6	4.1	75.9	4.1	77.1	4.2	86.1	4.6
4	7	60.2	0.6	80.7	0.9	84.4	0.9	88.5	0.4	98.0	0.1
5	18	58.2	1.4	83.3	1.8	82.5	1.8	85.7	1.9	95.8	2.0
6	26	59.8	1.8	80.9	0.6	85.7	0.6	88.3	0.5	97.6	0.2

Hardness of the wall horn was significantly greater for spring calvers in examination 5 only (Table 5.15). Overall there was no significant difference between calving season for unit 1.

Table 5.15 Comparison of hoof hardness (in shore A units) between calving season within unit 1

Site	Bulb			1			2		
Exam	Autumn	Spring	p	Autumn	Spring	p	Autumn	Spring	p
1	65.7 (0.65)	67.1 (1.5)	0.71	75.6 (9.5)	83.5 (1.1)	0.19	87.5 (1.2)	83.5 (0.8)	0.12
2	62.9 (1.6)	63.5 (1.3)	0.79	82.7 (1.0)	81.9 (0.9)	0.37	85.8 (0.8)	85.4 (1.4)	0.49
3	64.3 (1.5)	44.4 (8.6)	0.03	83.3 (0.7)	59.0 (11.5)	0.03	86.4 (1.1)	63.2 (12.3)	0.06
4	61.8 (0.9)	62.0 (1.0)	0.88	79.8 (0.7)	82.0 (1.0)	0.03	85.1 (0.9)	84.9 (1.3)	0.75
5	55.9 (3.7)	61.2 (1.9)	0.46	72.5 (5.0)	83.7 (1.0)	0.02	78.7 (5.0)	84.8 (1.1)	0.27
6	58.3 (4.8)	62.7 (1.0)	0.44	80.6 (0.6)	80.7 (0.7)	0.90	85.0 (0.9)	81.7 (1.0)	0.46
Site	3			Wall					
1	88.9 (0.7)	87.1 (0.7)	0.07	98.7 (0.2)	97.7 (0.2)	0.03			
2	87.4 (0.9)	89.8 (1.3)	0.22	98.8 (0.2)	98.1 (0.2)	0.08			
3	86.2 (2.5)	65.0 (12.6)	0.10	98.3 (0.2)	71.1 (13.8)	0.04			
4	88.4 (0.7)	88.4 (1.1)	0.90	98.1 (0.2)	98.0 (0.3)	0.98			
5	83.5 (5.3)	87.3 (0.6)	0.42	**91.9** (5.8)	**97.9** (0.1)	**0.006**			
6	88.0 (0.8)	86.4 (1.4)	0.61	97.8 (0.2)	98.4 (0.7)	0.30			

(standard errors are shown in brackets)

There was very little difference between heifers and cows within unit 1; however heifers had significantly harder walls ($p \leq 0.01$) in period 5 compared to cows (97.4, sem=0.1 vs 86.1, sem=12.3).

Within unit 1 there was no difference in hardness over time at the majority of sites i.e. bulb, 1, 2 or 3. There were significant hardness differences over time at the wall site ($p<0.01$) in that horn became softer around the time of parturition i.e. examination 3 (Table 5.16).

Table 5.16 Comparison of hoof hardness (in shore A units) between examinations within unit 1

Exam	Bulb		1		2		3		Wall	
Exam	Mean	sem	Mean	sem	Mean	sem	Mean	sem	Mean	sem
1	66.4	0.8	79.6	4.7	85.5	0.8	88.0	0.5	98.3	0.4
2	63.2	1.0	82.3	0.7	85.6	0.8	88.6	0.8	98.5	0.3
3	55.6	4.2	72.6	5.5	76.2	5.8	76.9	6.0	86.3	0.5
4	61.8	0.6	80.6	0.6	85.0	0.7	88.4	0.6	98.0	0.5
5	57.6	2.6	76.1	3.5	80.7	3.4	84.7	3.6	93.8	0.4
6	58.8	4.2	80.6	0.5	84.6	0.9	87.8	0.7	97.9	0.4

The wall horn was harder for unit 2 autumn calving animals during examination 2 only (Table 5.17). There were no other significant differences between calving season for hoof horn hardness during any other examination within unit 2.

Table 5.17 Comparison of hoof hardness (in shore A units) between calving season within unit 2

Site	Bulb			1			2		
Exam	Autumn	Spring	p	Autumn	Spring	p	Autumn	Spring	p
1	65.2 (1.5)	64.4 (1.7)	0.43	82.3 (2.1)	85.4 (1.6)	0.27	87.1 (1.4)	76.4 (9.6)	0.60
2	63.4 (1.5)	63.0 (1.9)	0.87	83.3 (1.1)	85.6 (1.4)	0.70	88.2 (1.6)	77.8 (11.2)	0.32
3	64.6 (1.3)	43.4 (9.5)	0.03	80.8 (0.8)	56.4 (12.3)	0.05	86.2 (1.0)	60.6 (13.3)	0.06
4	58.3 (1.4)	58.2 (0.8)	0.92	81.1 (0.7)	79.8 (1.6)	0.65	84.6 (1.8)	81.9 (4.3)	0.58
5	57.9 (1.0)	60.1 (1.3)	0.08	97.8 (17.9)	80.5 (1.34)	0.45	84.5 (0.9)	84.4 (1.0)	0.92
6	59.7 (1.0)	62.7 (2.5)	0.88	81.4 (1.1)	80.8 (1.5)	0.38	86.1 (0.8)	87.4 (1.6)	0.15
Site	3			Wall					
1	89.8 (1.3)	91.1 (1.3)	0.44	98.2 (0.6)	98.1 (0.3)	0.28			
2	88.7 (1.1)	91.2 (1.1)	0.18	**98.5** (0.3)	**97.9** (0.3)	**0.01**			
3	89.1 (0.9)	60.6 (13.3)	0.03	98.6 (0.2)	67.9 (14.8)	0.04			
4	88.7 (0.8)	88.5 (1.3)	0.17	98.1 (0.2)	97.8 (0.4)	0.62			
5	87.5 (1.0)	86.0 (0.9)	0.44	98.0 (0.1)	97.7 (0.3)	0.26			
6	89.2 (0.6)	87.5 (1.4)	0.82	97.4 (0.5)	97.7 (0.3)	0.72			

(standard errors are shown in brackets)

As with unit 1 animals there was little overall difference between heifers and cows, with the exception of period 4, where horn in site 3 was significantly harder for heifers (89.1 sem=0.7 vs 87.2 sem=1.2, p=0.01).

Between examinations there was a significant difference in the hardness at site 3 over time (p<0.01). The hoof horn in this area was softer at examination 3 compared to the previous 2 examinations (Table 5.18).

Table 5.18 Comparison of hoof hardness (in shore A units) between examinations within unit 2

Exam	Bulb		1		2		3		Wall	
Exam	Mean	sem	Mean	sem	Mean	sem	Mean	sem	Mean	sem
1	64.2	1.2	83.5	1.5	81.6	5.5	90.6	1.0	98.3	0.4
2	63.2	1.2	84.4	0.9	83.3	5.3	89.9	0.8	98.2	0.2
3	55.7	4.4	70.7	5.6	75.5	6.0	77.2	6.1	85.8	6.8
4	58.3	1.0	80.6	0.7	83.7	1.8	88.6	0.7	97.9	0.2
5	58.8	0.8	91.0	10.9	84.4	0.7	86.9	0.7	97.8	0.1
6	60.6	1.0	81.2	0.9	86.5	0.7	88.7	0.7	97.5	0.4

5.2.2 Hoof lesion results

As with the hoof measures the examinations were grouped into 6 periods defined in section 5.3.1.

Total lesion score

Median lesion score was significantly different between units (Kruskal-Wallis $p<0.01$) in the final hoof examination period-6 (Table 5.19). The rise in total lesion score was not surprising following calving (examination 3) however unit 2 seemed to sustain a higher level of lesion score for a longer period than unit 1.

Table 5.19 Median total lesion score between units

Examination period	Weeks post-calving	Unit 1	Unit 2	p
1	-14	3.0	5.0	0.09
2	-6	10.0	8.5	0.83
3	0.2	7.0	8.0	0.80
4	7	18.0	19.0	0.50
5	18	12.0	18.0	0.04
6	26	**7.0**	**14.0**	**0.005**

Within unit 1, calving season had no significant effect upon total lesion score (Table 5.20). However there was a strong trend for spring calvers to have higher lesion scores at calving.

Table 5.20 Comparison of total lesion score between calving season within unit 1

Examination period	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	3.0	2.0	0.29
2	-6	10.0	12.5	0.65
3	0.2	6.5	12.0	0.05
4	7	18.0	18.0	0.49
5	18	4.0	0.5	0.04
6	26	6.0	8.0	0.52

Within unit 2, calving season had no significant effect upon total lesion score ($p>0.01$). Autumn calvers however had a higher median lesion score both before and after calving, but not at calving (Table 5.21).

Table 5.21 Comparison of total lesion score between calving season within unit 2

Examination period	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	5.5	4.5	0.72
2	-6	9.0	7.0	0.35
3	0.2	8.0	12.0	0.55
4	7	19.0	19.0	0.70
5	18	20.0	13.0	0.07
6	26	14.5	10.0	0.90

From the median scores for each examination we can see that the precalving median scores are lower than the majority of the postcalving scores. (Table 5.22).

Table 5.22 Median total lesion score for each examination

Examination period	Weeks post-calving	Median total lesion score
1	-14	4.0
2	-6	9.5
3	0.2	8.0
4	7	18.5
5	18	15.0
6	26	10.0

An average lesion score for the two precalving examinations was calculated. The differences between this value and examinations 3 (at calving) and 5 (mid lactation) were analysed using Wilcoxon signed rank test; the null hypothesis being that the median did not differ from zero i.e. no change from precalving. There was a significant increase in total lesion score at exams 3 and 5 from a precalving score ($p<0.01$, Wilcoxon statistics= 739 and 786 for the median increase from precalving to scores in exams 3 and 5 respectively)

Front foot lesion score

Median lesion score in the front feet did not differ significantly between treatments (p>0.01). The lesion scores followed a similar pattern to the total feet scores in that unit 2 maintained higher median scores post-calving compared to unit 1 (Table 5.23).

Table 5.23 Effect of treatment on front foot median lesion score

Examination period	Weeks post-calving	Unit 1	Unit 2	p
1	-14	1.0	1.0	0.77
2	-6	4.0	3.0	0.22
3	0.2	3.0	2.5	0.56
4	7	5.5	6.5	0.61
5	18	3.5	4.0	0.85
6	26	2.0	3.0	0.42

There were no significant differences in median lesion score for the front feet between calving season within either unit 1 or 2 (p>0.01).

Front foot lesion scores were highest in examination 4 postcalving before falling in examination 5 and 6 (Table 5.24).

Table 5.24 Median front feet lesion score during each examination

Examination period	Weeks post-calving	Front feet lesion score (median)
1	-14	1.0
2	-6	3.0
3	0.2	3.0
4	7	6.0
5	18	4.0
6	26	2.0

Similarly to total lesion score, the change in front foot lesion score was analysed again using differences between precalving score and examinations 3 and 5. There was no significant increase or decrease from precalving score at examination 3 ($p>0.05$) however front foot score had increased significantly at examination 5 ($p<0.01$, Wilcoxon statistic= 645).

Hind foot lesion score

Median lesion scores for the hind feet differed significantly between treatments in examinations 1, 5 & 6 ($p\leq0.05$). Unit 2 consistently presented higher median hind feet lesion scores during these examinations, although median lesion score at calving was identical in both treatments (Table 5.25).

Table 5.25 Treatment effects on median hind feet lesion score for each examination

Examination period	Weeks post-calving	Unit 1	Unit 2	p
1	-14	**1.5**	**4.5**	**0.01**
2	-6	6.0	6.5	0.36
3	0.2	5.0	5.0	0.51
4	7	11.0	14.0	0.51
5	18	**8.0**	**14.0**	**0.01**
6	26	**6.0**	**11.0**	**0.001**

There was no significant difference in median hind foot score between calving season in unit 1 ($p>0.01$) (Table 5.26).

Table 5.26 Comparison of median hind feet lesion score between calving season within unit 1.

Examination period	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	3.0	1.0	0.45
2	-6	5.5	8.5	0.34
3	0.2	4.0	8.0	0.10
4	7	12.0	11.0	0.44
5	18	9.0	4.5	0.04
6	26	5.5	6.0	0.84

Within unit 2 there was no significant difference between calving seasons ($p>0.05$) (Table 5.27).

Table 5.27 Comparison of median hind feet lesion score between calving season within unit 2

Examination period	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	5.0	3.5	0.35
2	-6	7.0	6.0	0.65
3	0.2	5.0	5.5	0.48
4	7	13.0	15.0	0.54
5	18	16.5	9.0	0.06
6	26	11.0	9.0	0.92

Lesion score increased post-calving with maximum scores occurring at examination 4 before falling.(Table 5.28).

Table 5.28 Median hind feet lesion scores in each examination period

Examination period	Weeks post-calving	Hind feet lesion score (median)
1	-14	3.0
2	-6	6.0
3	0.2	5.0
4	7	12.5
5	18	11.0
6	26	8.0

There was a significant increase in hind foot lesion score in examinations 3 and 5 relative to the precalving examinations ($p<0.01$, Wilcoxon statistic 586 and 808 for the increases in watches 3 and 5 respectively).

Hind outer claws

As the greatest incidence of claw lesions is found in the outer hind claws, this is possibly the area which shows the greatest variability in terms of lesion development and this area has been specifically analysed.

Treatment effects

There were significant treatment effects post-calving on lesion score in the left hind outer claw only ($p<0.01$). Unit 2 had significantly higher median lesion scores for the left hind outer claw in examinations 5 and 6 (Table 5.29). Furthermore there was a strong trend for unit 2 to have higher median lesion scores in examinations 1, 2 and 4.

Table 5.29 Comparison of treatment effects on outer claw lesions

		Left hind outer claw (median)			Right hind outer claw (median)		
Hoof exam	Weeks post-calving	Unit 1	Unit 2	p	Unit 1	Unit 2	p
1	-14	1.0	1.5	0.07	0.0	0.0	0.37
2	-6	1.0	3.0	0.08	0.0	0.0	0.39
3	0.2	1.0	1.0	0.34	1.0	1.0	0.93
4	7	3.0	4.0	0.07	1.5	2.5	0.05
5	18	**1.5**	**5.0**	**0.008**	1.0	1.0	0.85
6	26	**1.0**	**4.0**	**0.002**	1.0	1.0	0.19

The combined lesion score for both left and right hind outer claws showed that there was no significant difference between treatment in the first 5 examinations although in some examinations there was a strong trend for unit 2 to have higher total lesion scores (Table 5.30). Furthermore unit 2 had significantly higher total lesion in examination 6 ($p<0.01$)

Table 5.30 Treatment effects on total lesion score in the outer hind claws

Hoof exam	Weeks post-calving	Unit 1	Unit 2	p
1	-14	1.0	2.0	0.047
2	-6	2.0	3.0	0.24
3	0.2	2.0	2.0	0.33
4	7	5.0	7.0	0.07
5	18	4.0	7.0	0.04
6	26	**2.0**	**6.0**	**0.001**

Spring calvers in unit 1 had significantly more lesions around calving, examination 3 than autumn calvers (Table 5.31).

Table 5.31 Calving season effects on total median lesion score in the outer hind claws within unit 1

Hoof exam	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	1.0	1.0	0.43
2	-6	1.5	3.5	0.19
3	0.2	**1.0**	**3.0**	**0.007**
4	7	5.0	5.0	0.95
5	18	4.5	3.5	0.59
6	26	1.5	3.0	0.34

In contrast to unit 1 there was no significant difference between autumn and spring calvers in unit 2 (Table 5.32).

Table 5.32 Calving season effects on total median lesion score in the outer hind claws within unit 2

Hoof exam	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	1.5	2.5	0.43
2	-6	3.0	2.0	0.91
3	0.2	2.0	3.0	0.17
4	7	7.0	7.0	0.66
5	18	7.0	6.0	0.86
6	26	6.0	4.0	0.85

Hoof hardness, wear and hoof horn lesions

The relationship between hoof horn hardness, wear and the development of lesions was investigated using Spearman rank correlations. There was no significant relationship between change in hardness in the outer right hind claw and expression of lesions in that claw (Table 5.33).

Table 5.33 Correlation matrix between hoof hardness lesions growth and wear

			Lesions at claw site							
Hardness site	Growth	Wear	1	2	3	4	5	6	Heel erosion	Total claw lesion score
bulb	0.01	-0.02	0.03	0.01	-0.24	-0.20	-0.08	-0.09	0.01	-0.22
1	-0.02	-0.01	0.00	0.01	-0.17	-0.15	-0.18	-0.05	0.02	-0.15
2	-0.01	-0.03	0.01	-0.04	-0.20	-0.23	0.15	0.00	0.01	-0.15
3	-0.00	-0.01	0.05	0.04	-0.24	-0.22	-0.22	-0.02	0.08	-0.18
Wall	0.02	-0.03	0.06	0.04	-0.24	-0.22	-0.02	-0.02	0.08	-0.16

df=52 , Significance level 1%= 0.354.

Heel erosion

Heel erosion score did not differ significantly between units (p>0.05), although unit 2 score remained higher compared to unit 1 post-calving (Table 5.34).

Table 5.34 Comparison of total heel erosion score between units

Examination period	Weeks post-calving	Unit 1	Unit 2	p
1	-14	0.0	0.0	0.67
2	-6	0.0	0.0	0.67
3	0.2	0.0	0.0	0.07
4	7	5.0	4.0	0.47
5	18	2.0	8.0	0.78
6	26	1.0	6.0	0.14

Median total heel erosion score i.e. summed scores for all claws, were higher post-calving (Table 5.35).

Table 5.35 Median heel erosion score in each examination period across all animals

Examination period	Weeks post-calving	Total heel erosion score (median)
1	-14	0.0
2	-6	0.0
3	0.2	0.0
4	7	5.0
5	18	5.0
6	26	3.0

There was no significant change in heel erosion score at examination 3 (calving) from the previous precalving examinations (p>0.01; Wilcoxon statistic =55).

However heel erosion score increased significantly in examination 5 compared with the precalving examinations ($p<0.01$, Wilcoxon statistic= 335).

Within unit 1 autumn calvers had significantly higher heel erosion scores precalving in examination 1, and post-calving in examinations 5 and 6 ($p<0.01$) (Table 5.36).

Table 5.36 Calving season effects on heel erosion within unit 1

Examination period	Weeks post-calving	Autumn	Spring	p
1	-14	**4.0**	**0.0**	**0.001**
2	-6	0.0	0.0	0.47
3	0.2	0.0	2.0	0.02
4	7	5.0	7.0	0.38
5	18	**9.0**	**0.0**	**0.009**
6	26	**8.0**	**0.0**	**0.001**

Unit 2 autumn calvers had consistently higher heel erosion both before and after the event of calving in examinations 1, 5 and 6 ($p<0.01$) (Table 5.37).

Table 5.37 Calving season effects on heel erosion within unit 2

Examination period	Weeks post-calving	Autumn	Spring	p
1	-14	**1.5**	**0.0**	**0.005**
2	-6	0.0	0.00	0.21
3	0.2	0.0	0.0	0.15
4	7	6.0	2.0	0.05
5	18	**10.0**	**0.0**	**0.001**
6	26	**9.0**	**0.0**	**0.003**

Interdigital and digital dermatitis score (IDD & DD)

There was no significant difference in IDD score between units in any of the hoof examination periods (Table 5.38).

Table 5.38 Effect of treatment on IDD score

Examination period	Weeks post-calving	Unit 1 median	Unit 2 median	p
1	-14	0.0	0.0	0.80
2	-6	0.0	0.0	0.30
3	0.2	0.0	0.0	0.32
4	7	0.0	0.0	0.13
5	18	0.0	1.0	0.21
6	26	0.0	1.0	0.16

IDD increased in incidence in the post-calving examinations 4, 5 and 6 shown by the median scores in each examination below (Table 5.39).

Table 5.39 Comparison of median IDD scores between each hoof examination

Examination period	Weeks post-calving	Total IDD score (median)
1	-14	0.0
2	-6	0.0
3	0.2	0.0
4	7	5.0
5	18	5.0
6	26	3.0

IDD scores in examination 3 did not change significantly from precalving levels ($p>0.05$, Wilcoxon statistic= 67). However IDD score had increased significantly in examination 5 ($p<0.01$, Wilcoxon statistic =298).

Unit 1 spring calvers had a significantly higher IDD score in examination 2 compared to autumn calvers. Autumn calvers however had a higher IDD score postcalving during examination 6 (Table 5.40).

Table 5.40 Calving season effects on IDD score within unit 1

Examination period	Weeks post-calving	Autumn calvers	Spring calvers	p
1	-14	0.0	0.0	0.75
2	-6	**0.0**	**5.0**	**0.005**
3	0.2	0.0	0.0	0.43
4	7	0.0	0.0	0.12
5	18	0.0	2.0	0.20
6	26	**2.0**	**0.0**	**0.007**

The incidence of IDD within unit 2 was not significantly affected by calving season during any examination period ($P>0.1$) (see appendix).

Digital Dermatitis

There were no significant effects of treatment on median DD score in any of the examination periods ($p>0.05$) (see appendix).

The median DD scores in each examination period did not show any change from zero (Table 5.41).

Table 5.41 Comparison of median DD score between examination periods

Examination period	Weeks post-calving	Total DD score (median)
1	-14	0.0
2	-6	0.0
3	0.2	0.0
4	7	0.0
5	18	0.0
6	26	0.0

There was no significant change in DD score in examinations 3 or 5 relative to the precalving examinations (p>0.05, Wilcoxon statistics= 10 and 69 for exams 3 and 5 respectively).

There was no significant effect of calving season on the extent of DD in either unit (p>0.05).

5.4 Discussion

There were measurable effects of treatment on various claw parameters and lesion severity and expression.

5.4.1 Lesions

<u>Total lesion score</u>

Treatment had a significant effect on the total lesion score in the late post-calving examinations. Animals within unit 2, the high input unit, sustained a high lesion score in examination 6 relative to unit 1, the low input unit. However peak lesion score did not differ between treatments and neither did precalving lesion score. The high production levels together with increased use of concentrate appeared to sustain the development of lesions for a more prolonged period. It is suggested that lesions developed by unit 2 animals are influenced by the causative factors associated with the high input management, long after the effects which initiated peak lesion development have occurred.

The data also provided support for a behavioural influence; in chapter 4 it was shown that lying time of unit 1 animals fell in the immediate post-calving period relative to unit 2. This treatment effect on behaviour may have exacerbated lesion development but once lying time had stabilised then the risk fell and subsequently lesions declined. Overlying these dietary, production and behavioural influences was the possible effect termination of housing time had upon unit 1, the low input unit: this herd was turned out 2-3 weeks before unit 2, which allowed them a period of recuperation earlier in lactation relative to unit 2.

There was no significant effect of calving season on total lesion score. However there were strong trends for unit 1 autumn calvers to have a lower score at calving and a higher score mid lactation. Over the entire study period, these differences were transient and may not fully reflect the risks due to calving and housing factors.

Lesion development followed a similar pattern across all animals, in that peak lesion score occurred during examination 4 i.e. 2-3 months post-calving whilst the lowest score occurred during exam 1. Calving was evidently the initiating factor, or marked a period where all risk factors interacted resulting in a dramatic rise in subclinical lesion incidence.

Front feet lesion score

Management and production had no effect upon development of lesions across all hoof examinations. In terms of lesion distribution the front feet expressed a relatively small proportion of lesions compared to the hind feet. Therefore the effect of treatment in such a small number of lesions would not have been as apparent. The pattern of lesion development followed an identical trend to that of overall lesion score: maximum lesion expression occurred following calving, i.e. examination 4, before falling in the final 2 examinations.

Hind feet lesion scores

The hind feet, and especially the outer hind claws, present the largest proportion of lesions in terms of number and severity. Many theories have been postulated for this, ranging from increased weight bearing in this area at critical times (Arkins 1981), udder displacement forcing hocks outward (Webster, 1995), increased weight of conceptus on these feet precalving (Scott, 1987), and the effect of animals standing half in cubicles placing more weight on the hind claws. However hind feet carry less weight than the front feet (Scott,1987; 1989), suggesting that there are other factors at work here than just weight bearing *per se*.

There were treatment differences in that lesion scores in unit 1, the low input unit, were significantly lower on pasture, examination 1 precalving and examinations 4 and 5 post-calving.

The outer hind claws were analysed separately as this area showed the majority of lesion expression. Unit 1 presented significantly less lesions overall in examinations 5 and 6. Within unit 1, factors influencing the development of lesions, such as calving and a compromised lying time in early lactation, were ephemeral over the housing period. Subsequently, once peak lactation occurred, these effects were greatly reduced and lesion scores fell. In comparison, the risk factors associated with concentrate feeding and high milk output remained over the entire post-calving housing period within unit 2, the high input unit; this is possibly the reason why lesion scores in that unit remained relatively high late into the post-calving period. Claw horn lesions were more common in the left hind outer claw of unit 2 animals in certain examinations. There was no immediately apparent explanation for this difference but the non-symmetrical expression of lesions between left and right claws will be investigated during future analysis of this data by the research group.

Heel erosion

Heel erosion is one of the primary diseases afflicting hooves in the immediate housing period. Treatment had no significant effect on heel erosion possibly because the immediate housing environment was a more potent factor than dietary or management effects on disease incidence. The level of heel erosion rose sharply post-calving. This pattern of development and incidence is in close agreement with a study by Enevoldsen *et al* (1991b) where he compared early lactation with prelactation, and attributed the increased risk to housing environment exposure. If this held true then spring calvers should have higher heel erosion scores around calving and autumn calvers should have increased heel erosion later in lactation. This postulated difference in disease incidence was seen within unit 1 only, where spring calvers had a higher heel erosion score at calving and a significantly lower score in later examinations 5 and 6. Unit 2 spring calvers did not seem to have a high heel erosion score at calving, but autumn calvers on this unit had a constantly high heel erosion score post-calving, reflecting the longer time these animals were housed.

Interdigital and digital dermatitis

Treatment appeared to have no effect on digital or interdigital dermatitis perhaps because this is primarily a problem of infection via the environment. As the housing conditions were identical between units the risk factors within each unit were probably equal.

Infectious disease incidence increased post-calving. The rise was possibly attributed to the additive risk of exposure to the housing environment coupled with the increased movement to and from the milking parlour which would increase the overall risk of contacting the infectious agent. Between units, calving season had little overall effect, however in unit 1 spring calvers had a significantly higher IDD score in examination 2 (6 weeks precalving), compared to autumn calvers. A possible explanation for this could be the immediate effect of housing and the fact that the animals had a very small area of housing (due to their smaller group size): therefore if one animal had contracted an infectious interdigital disease the likelihood of another animal in that group succumbing would have been increased.

5.4.2 Physical characteristics of the hoof

Hoof angle

The analysis indicated that treatment had no effect on hoof angle, however the changes in hoof angle over the calving period were very similar in each unit. As described by Offer *et al* (1997), hooves became steeper post-calving, contrary to popular opinion which implies hooves become overgrown throughout the housing period leading to shallower hoof angles (Rowlands *et al*, 1983). These findings suggest that either hooves wear faster at the toe, or that the heel grew at a faster rate than the rest of the hoof, or possibly a combination of these two factors, raising the hind part of the claw and hence increasing the angle of the entire claw. As heels are usually the first area to erode on entry to housing (Enevoldsen *et al*, 1991b) the findings imply that horn at the toe is eroded at a faster rate than the rest of the claw.

The frequency of trimming increased as the onset of calving approached, therefore an alternative cause of the increase in claw angle could be the additive effect of removal of sole horn during each progressive examination. Data from Manson & Leaver (1988b) showed that untrimmed claws were significantly shallower during week 3 to 26 of lactation compared to regularly trimmed claws. The amount of horn removal during each examination in the present study was as small as possible, usually no more than the very uppermost soiled horn. It is unlikely that this would result in such a major change in claw angle.

All animals had claw angles which fell within the optimum 45-55° angle: such angles are associated with a reduced risk of clinical lameness (Blowey, 1993; Toussaint-Raven, 1985). No animal on trial became severely clinically lame over the entire study period. One heifer in unit 2 did suffer with IDD causing her to be recorded as lame for one week only in the autumn of 1995 however an infection in the interdigital area is unlikely to be strongly linked to hoof angle.

<u>Claw length, growth and wear</u>

Treatment had no significant effect on the length of the right hind claws. This is possibly genetically pre-determined and very resistant to nutritional factors imposed upon the animal. All heifers were raised more or less identically until they became reproductively mature, therefore the effects of dietary treatment during lactation had little time to affect the mature claw size. This is in agreement with previous studies which demonstrated that the level of concentrate inclusion in cow diets had no significant effect on claw length (Leach *et al* 1997; Manson & Leaver 1988a).

Within each unit there were significant calving season differences in claw length. Autumn calvers had significantly longer claws compared to spring calvers after calving, i.e. early to mid lactation. This appeared to be primarily an effect of housing, as spring calvers at this particular time relative to calving had been housed for a comparatively longer time period than autumn calvers. The longer exposure to erosive factors in the housed environment, i.e. concrete abrasion and slurry exposure, resulted in reduced claw lengths at the above time.

Claw growth was unaffected by treatment and remained fairly consistent between examinations, a result similar to a previous study by Leach *et al* (1997). There were no discernible calving season effects within unit 1, the low input unit; however unit 2 autumn calvers had significantly less growth compared to spring calvers in early lactation (examination 4). The additive trauma of calving and lactation possibly interrupted or dramatically reduced horn growth for this calving group. However over the entire examination period, units did not differ in overall growth and wear ($P>0.05$).

Calving season had definite effects upon hoof wear within unit 1. The extent of erosion in the hooves of spring calvers during examination 2 was significantly higher compared to autumn calving animals presumably due to their longer exposure to the housed environment prior to parturition. The wear in the spring calver's hooves fell significantly relative to autumn calvers during examination 5 presumably due to the beneficial effect turnout had on hoof recovery.

The difference between autumn and spring calvers was not evident within unit 2, possibly as a result of the reduced standing time displayed by these animals in the early post-calving period reducing the extent of hoof erosion.

<u>Hoof hardness</u>

There was very little difference between high and low input units in terms of hoof hardness. Hardness measurements were taken by the same person throughout the study as measures proved too inconsistent between individual recorders to be justifiably used. There is a large human error factor associated with the use of the hardness meter, and data collected should be viewed as a relative not an absolute measure of the hardness of claw horn. Accepting that there is a large error margin, the most interesting finding is that changes in hoof hardness followed a similar trend at all of the measured sites, in that hooves were generally softer at calving (examination 3) than during any other time. Hoof hardness precalving (examination 1) equated fairly consistently with hardness post-calving (examinations 5 and 6). This dynamic pattern of hardness change from calving onward concurs with the study by Offer *et al* (1997). It is possible that the additive effect of the increased frequency of claw trimming at this time exposed softer underlying hoof horn and was responsible for the changes seen.

Calving season had similar effects in both units. The main effect was that spring calvers had significantly softer hooves at calving, presumably because spring calvers were exposed to erosive and slurry effects in the housed environment for a longer period relative to autumn calvers. A further difference was observed within unit 1 where autumn calvers had significantly softer hooves at 1 site in examination 5, this possibly shows that at this stage relative to calving the autumn calvers were still housed, whilst the spring calvers were out at pasture allowing the hooves to recover from the detrimental effect of housing, however the overall effect appeared to be minor.

In conclusion treatment (diet and management) had significant effects on lesion expression particularly in sustaining high lesion scores late into the post-calving period. Treatment had little effect on the physical characteristics of the hoof or the extent of growth and wear suggesting that these factors are not strongly influenced by management and diet.

6 Relationship between behaviour and lesions

6.1 Introduction

The interaction between behaviour, environment and the development of lesions has been poorly studied. It would seem logical that animals that lie for longer place less stress on their hooves, and that this would lead to fewer lesions developing in the claws. Some studies have inferred that increasing lying time does in fact reduce the level of either subclinical or clinical lameness or both. Colam-Ainsworth *et al* (1989) reported that a herd of cubicle housed cows provided with additional straw bedding showed less lameness than a herd provided with little straw, and that the cows utilised the cubicles to a greater extent in the period between 22.00 to 03.00 daily. However no records of total daily lying time were made, which is important as cows will often lie in cubicles during the daytime. Furthermore there also could have been a beneficial effect of the increased straw which if eaten in large enough quantities would have a stabilising effect on the rumen mediated through increased saliva production. Stable rumen conditions greatly reduce the risk of laminitis from acidosis or other nutritional factors. Singh *et al* (1994) reported that on one farm where housing was switched from cubicles to straw yards, cows lay for longer and this had beneficial effects on claw health. However, there is a confounding factor in that a straw covered surface is far softer than bare concrete, and this factor may possibly have promoted better claw health. One of the few studies to directly investigate the effects of behaviour on lameness was conducted by Leonard *et al* (1994) where the behaviour of cows was recorded in 2 situations; when the cow:cubicle ratio was 1:1 and when it was almost 2:1. The findings showed that cows in the crowded situation stood for longer and lay for less time and had a higher incidence of subclinical lesions in their claws.

If lying time is one component of an animal's activity budget, then standing time, and more importantly what cows do whilst standing, must surely be as relevant. The respective behaviours expressed whilst standing place different stresses on the hooves. Walking in particular places an increased force on the hooves and it is likely this is increased when turning due to the shearing forces involved. However cows need to undertake a certain amount of daily locomotion to maintain normal blood supply in the hooves and keep joints and limbs supple. There is a behavioural requirement of cows to explore or patrol their immediate environment (Wood-Gush *et al*, 1983). Therefore reducing the amount of excessive walking animals are able to perform may have benefits for hoof health, but the advantages are perhaps partly offset by a reduced ability to express natural behaviour patterns.

Social behaviour also has some influence on lesion development, mediated through actions to avoid confrontation. Galindo & Broom (1993) suggested that submissive cows were more easily displaced and had increased walking and standing times, which in turn increased the incidence of clinical lesions in these animals. However a relationship between rank and lameness may also suggest that cows which have more lesions are in pain and are more easily displaced because of this. Heifers are particularly vulnerable and often have increased hoof lesions (Bazeley & Pinsent, 1984; Colam-Ainsworth *et al*, 1989).

The previous chapters have concentrated on treatment effects and have considered the animals as groups rather than as individuals. In this chapter individual animals' behaviour will be analysed with respect to the calving period and relevant lesion scores.

6.2 Methods

6.2.1 Animals

All 1^{st} and 2^{nd} lactation animals from each unit were used in this study for further details see section 4.2.1. The animals consisted of 56 high genetic merit Holstein Friesian cows. These animals are described in greater detail in chapter 2, 4 and 5 as cohorts I and II.

6.2.2 Housing and diets

Animals were housed in a large cubicle building a plan of which is given in section 2.4. The diets consisted of a complete mix of grass clover or grass silage with varying amounts of draff and parlour concentrate; for further details refer to section 2.6.

6.2.3 Hoof examination

All feet were examined routinely in relation to the calving and housing period. Feet were scored for a variety of lesions, in both extent and frequency. Parameters scored were horn lesions, heel erosion and interdigital and digital disease using a respective subjective scoring systems for each disease type. For further details refer to section 2.8.1 and chapter 5.

6.2.4 Behavioural observation

Animals were observed pre and post-calving at 2 week intervals throughout the housing period. Further details can be found in chapter 2, section 2.7.3.

6.2.5 Statistical analysis

Each examination period was analysed separately, and periods 1-6 were used as described in the previous chapter (Table 5.1). The behaviour watches were grouped as far as possible into the same timescale categories as the hoof examination periods. If there were 2 or more watches in one period, then the mean of scans were calculated for each behaviour parameter used in the correlation.

As factor scores, behavioural scan measurements and lesion scores were not normally distributed, the relationship between these factors was analysed using Spearman rank correlations. Actual percentages of scan behaviour values were initially ranked to correlate against lesion score. Due to the total number of correlations made for each examination period, it was decided to reduce the criterion of significance to $p=0.01$, to place more emphasis on meaningful correlations rather than a random chance correlation. The sign (positive or negative) of all correlations is shown, even if they are non-significant, together with correlation coefficients that correspond to $p<0.05$.

6.3 Results

6.3.1 Correlations between behavioural variables expressed as % of scans and lesion scores

The interrelation between behaviour and lesions was extremely variable. In the examinations prior to calving, the behaviours which had the strongest relationship with lesion expression were cubicle orientated standing behaviours (Tables 6.1 and 6.2). These were negatively correlated with both front feet lesions and total lesion score. Standing ruminating within the cubicle in examination period 2 was positively correlated with the degree of interdigital dermatitis. At calving (Table 6.3) there was no significant relationship between behaviour and the various lesion parameters measured, however, within this period, total standing in the cubicle showed a positive correlational trend with almost all lesion scores.

In the early post-calving examination period, where peak lesions were expressed (period 4), the effect of cubicle standing behaviour re-emerged in that this type of standing behaviour was negatively associated with lesion development, particularly in the front feet (Table 6.4). However standing within the cubicle had no significant relationship with hind foot lesion expression and there was a negative trend between these variables. Further into lactation (examinations 5 and 6) lying time showed a significant trend in that front inner claw scores were negatively associated with lying time, but heel erosion was positively associated with lying time. Also at this time, the trend that standing within the cubicle was negatively associated with lesion development, reversed in examinations 5 and 6 (Tables 6.5 & 6.6). Feeding time across all examination periods was consistently positively associated with front inner claw scores.

For all the following tables the positive and negative signs indicate the relationship between behaviour and lesions for non-significant correlation coefficients.

Table 6.1 Period 1 rank correlations between behaviour and lesions

n=52	Stand inactive	Stand inactive in the cubicle	Stand ruminate	Stand ruminate in the cubicle	Stand feed	Total stand cubicle	Lying ruminating	Lying Inactive	Total lying time
Front inner claw score	+	-	+	-0.67 **	+	-0.69**	+	-	+
Front foot total score	-	-	+	-0.52•	+	-0.59**	+	-	+
Hind outer score	-	-	+	-	+	-	-	+	-
Hind feet total score	-	-	+	-	+	-	+	+	+
Total lesion score	-	-	+	-	+	-0.59**	+	+	+
Heel erosion score	+	+	+	-	+	-	-	-	-
DD score	+	+	+	-	+	-	-	-	-
IDD score	+	+	+	-	+	-	-	-	-

(**indicates p<0.01, •indicates p<0.05)

Table 6.2 Period 2 rank correlations between behaviour and lesions

n=52	Stand inactive	Stand inactive in cubicle	Stand ruminate	Stand ruminate in cubicle	Stand feed	Total stand cubicle	Lying ruminating	Lying Inactive	Total lying time
Front inner claw score	+	+	+	+	-	+	-	-	-
Front foot total score	+	+	+	+	-	+	-	-	-
Hind outer score	**-0.46**•	+	-	+	+	-	+	+	+
Hind feet total score	-	+	-	-	+	+	+	+	+
Total lesion score	-	+	-	+	+	+	+	-	-
Heel erosion score	+	+	-	+	-	+	-	-	-
DD score	-	-	-	+	+	-	+	-	-
IDD score	+	+	-	**0.55****	-	+	-	-	-

(**indicates $p<0.01$, •indicates $p<0.05$)

Table 6.3 Period 3 rank correlations between behaviour and lesions

n=52	Stand inactive	Stand inactive in cubicle	Stand ruminate	Stand ruminate in cubicle	Stand feed	Total stand cubicle	Lying ruminating	lying Inactive	Total lying time
Front inner claw score	-	+	+	+	+	+	-	-	-
Front foot total score	+	+	+	+	+	+	-	+	-
Hind outer score	-	+	+	+	+	+	+	-	+
Hind feet total score	+	+	+	-	-	-	-	+	+
Total lesion score	+	+	+	-	-	+	-	+	-
Heel erosion score	+	+	+	+	-	+	-	+	+
DD score	-	-	+	+	+	+	-	-	-
IDD score	+	-	-	-	-	-	+	+	+

Table 6.4 Period 4 rank correlations between behaviour and lesions

	Stand inactive	Stand inactive in cubicle	Stand ruminate	Stand ruminate in cubicle	Stand feed	Total stand cubicle	Lying ruminating	Lying Inactive	Total lying time
Front inner claw score	-	-0.36•	-	-	+	-0.40**	+	-	+
Front foot total score	+	-0.40**	-	-	-	-0.37•	+	-	+
Hind outer score	-	-	-	-	-	-	+	+	+
Hind feet total score	-	-	-	-	-	-	+	+	+
Total lesion score	-	-0.40**	-	-	-	-0.34•	+	+	+
Heel erosion score	-	+	-0.33•	-0.38•	+	-	+	+	+
DD score	+	+	-0.30•	-	+	-	+	-	+
IDD score	-	+	-	-	+	-	+	-	+

(**indicates p<0.01, •indicates p<0.05)

Table 6.5 Period 5 rank correlations between behaviour and lesions

	Stand inactive	Stand inactive in cubicle	Stand ruminate	stand ruminate in cubicle	Stand feed	Total stand cubicle	Lying ruminating	lying Inactive	Total lying time
Front inner claw score	-	0.39•	+	0.41•	+	0.43•	-0.48**	-	-0.38•
Front foot total score	-	0.37•	+	+	+	+	-0.34•	+	-
Hind outer score	-	+	-	+	+	+	-	+	+
Hind feet total score	-	-	-	-	+	-	+	+	+
Total lesion score	-	+	-	+	+	+	-	+	+
Heel erosion score	-0.39•	-	-	-	-	-0.39•	+	0.42•	0.44•
DD score	+	-	+	+	+	+	-	+	-
IDD score	-	-	-	-	-	-	-	+	-

(**indicates p<0.01, •indicates p<0.05)

Table 6.6 Period 6 rank correlations between behaviour and lesions

	Stand inactive	Stand inactive in cubicle	Stand ruminate	Stand ruminate in cubicle	Stand feed	Total stand cubicle	Lying ruminating	Lying Inactive	Total lying time
Front inner claw score	+	-	-	+	+	+	+	-	-
Front foot total score	+	-	-	+	-	+	+	-	-
Hind outer score	+	**0.40**•	-	-	-	+	-	-	-
Hind feet total score	+	+	-	+	-	+	-	-	-
Total lesion score	+	+	-	+	-	+	-	-	-
Heel erosion score	-	+	+	**-0.42**•	-	-	+	+	+
DD score	**0.38**•	-	+	+	-	-	-	-	-
IDD score	-	+	+	+	-	+	+	-	-

(**indicates $p<0.01$, •indicates $p<0.05$)

There seemed to be a definite split in the effects of cubicle and non-cubicle orientated behaviour, therefore all behaviour performed in the cubicle (both standing and lying) was grouped to obtain a value for cubicle occupation, expressed as a % of total scans. This value for cubicle occupation was calculated for each examination period and correlated with the lesion scores in each examination (Table 6.7). The effect of total cubicle occupation was only significant in period 1 where it had a negative relationship with front foot lesions and hind outer lesions. This suggests that animals that occupied the cubicle for longer had less severe or fewer lesions in both the front feet and more crucially the hind outer claws (Table 6.7).

Table 6.7 Rank correlations between total cubicle occupation and lesions across all examinations

	Total cubicle occupation (% of scans)					
	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Front inner claw score	**-0.61****	-	-	-	-	-
Front foot total score	**-0.67****	-	-	-	-	-
Hind outer score	**-0.58****	+	+	+	+	+
Hind feet total score	-	+	-	+	+	-
Total lesion score	-	+	-	+	+	-
Heel erosion score	-	-	+	+	+	+
DD score	-	-	-	-	-	-
IDD score	-	-	-	+	-	-

(**indicates $p<0.01$, *indicates $p<0.05$)

So far the behaviour and lesion scores have been directly compared e.g. the behaviour in period 1 was compared with lesions in period 1. There may possibly be a lag in the response of the lesion scores to an animal's activity pattern due to the time it takes for lesions to move from the surface of the corium so that they become visible in the outermost sole horn (Leach *et al*, 1997). To account for this effect (if any), it was appropriate to compare lesion scores with the behaviour expressed during the previous examination period, for example period 2 lesions with period 1 behaviour.

There were no significant correlations between lesions in examination periods 2, 3, 5 and 6 and behaviour previously expressed during examination periods 1, 2, 4 and 5 respectively (P<0.05). Certain behaviours during period 3 significantly correlated with lesions found during period 4. Standing inactive in the passageway was positively correlated with subsequent total hindfeet score and heel erosion score ($r=0.419$ and 0.440, $p<0.01$).

6.3.2 Relationship between factor scores and lesions

Factor scores were calculated for each individual animal from the loading coefficients given for the behavioural variables.

Three factor scores for each animal were rank correlated against both mean lesion score and summed lesion scores over the watch periods included in the factor analysis i.e. watch 5-12. Due to the numerous correlations made the level of significance was again taken as 1%. For more detail of the behavioural loadings in each of the three factors generated see section 4.3.3.

The mean lesion scores over the watches 5-12 showed that lesions were significantly correlated with factors 1 and 3, but not with factor 2. Factor 1 which loaded heavily positive for standing inactive in the cubicle and heavily negative for lying ruminating was shown to be negatively correlated with both heel erosion score and DD score. This meant animals that had low factor scores for factor 1 were those which either stood longer in the cubicle, or lay longer and ruminated had the lowest heel erosion and digital dermatitis scores (Table 6.8).

Factor 2 seemed to have no significant relationship with lesion score. This factor loaded heavily negative for behaviours that were associated with standing in the slatted and feed passageway. It is therefore reasonable to assume that these behaviours had a weak relationship with the expression of subclinical disease (Table 6.8). This was in agreement with the direct behavioural comparisons (Tables 6.1-6.6).

There are significant relationships between factor 3 and various hoof lesion parameters. Factor 3 is positively loaded for standing feeding and negatively for lying inactive. There is a significant negative correlation between this factor and hind foot score. There is also a strong trend for front foot lesion score to correlate positively, and total lesion score, similar to hindfoot score, to correlate negatively. This means that animals that lay inactive for longer or fed for less time would show more hind foot and hence overall lesions. The reverse is also true, that animals that either lay inactive for less time and/or fed for longer would have less severe hindfoot lesions (Table 6.8).

Table 6.8 Spearman rank correlation between factor scores and mean lesion scores across watches 5-12

Mean	Factor score 1	Factor score 2	Factor score 3
Front inner score	+	-	**0.33●**
Front total score	+	-	+
Hind outer score	-	+	-
Hind total score	-	+	**-0.39****
Total lesion score	-	+	**-0.30●**
Heel erosion score	**-0.44****	+	-
DD score	**-0.37****	+	+
IDD score	+	-	+

(●indicates $p<0.05$, ** indicates $p<0.01$)

The correlations for the factor scores and the summed lesion scores followed the same pattern as the mean lesion scores (Table 6.9). Factor 1 negatively correlated with heel erosion and digital dermatitis summed lesion score. There was also a strong trend for interdigital dermatitis score to correlate negatively with this factor. Individuals scoring highly for factor 1 would either lie and ruminate for less time, or stand in the cubicle for longer; they also would express a lower incidence of the above diseases.

Factor 2 had no significant relationship with any summed lesion score parameter. This factor loaded heavily for standing in the passage but apparently this had no influence on total lesion scores expressed.

Factor 3's relationship with the summed lesion parameters was identical to that of the mean lesions. Factor 3 was negatively correlated with summed hind foot lesion score. There is also a strong trend for front foot lesion score to correlate positively, and total lesion score, similar to hindfoot score, to correlate negatively. Again animals that fed for longer or lay inactive for less time would have had a high factor score and correspondingly have low hind foot and hence lower total lesion score. Conversely animals that had a low factor 3 score i.e. individuals that fed for shorter times or lay inactive for longer, had the reverse relationship on the summed scores described above.

Table 6.9 Spearman rank correlations between factor scores and summed lesion scores across watches 5-12

Summed	Factor score 1	Factor score 2	Factor score 3
Front inner score	-	-	**0.29●**
Front total score	+	+	+
Hind outer score	-	+	-
Hind total score	-	+	**-0.37****
Total lesion score	-	+	**-0.29●**
Heel erosion score	**-0.43****	+	-
DD score	**-0.38****	-	+
IDD score	**-0.28●**	+	+

(●indicates $p<0.05$, ** indicates $p<0.01$)

6.4 Discussion

6.4.1 Direct comparison

The relationship between behaviour and lesions throughout the examinations was highly variable, perhaps indicating that different behaviours became more incidental in the development of subclinical lesions at specific times in relation to calving. The lesions recorded must be considered to be subclinical as no cows were observed to be lame on the Manson & Leaver scoring system.

The behaviours associated with standing in the cubicle area were negatively correlated with lesions especially in the front feet. Most cows adopt a half in-half out position when standing in the cubicle where front feet are placed in the cubicle area and the hind feet remain in the slatted passage. There were very few animals able to stand for any length of time with all four feet in the cubicle with their heads raised over the headrail, due to this structure impeding any forward movement. Less than 1% of all cubicle standing behaviour was recorded with animals standing fully in, most animals adopting the half-in, half-out posture. One reason for this was presumably the head rail impeding forward movement. Furthermore the cubicles are now 20 years old and due to genetic selection the animals today are larger than the animals for which the cubicles were initially built. By raising the front feet in relation to the hind feet, the animal may transfer a greater proportion of its weight to the hindfeet: this possibly benefits the health of the front feet by reducing the risk of lesion development. This effect may be accentuated by the fact that the deformable sawdust bedding within the cubicle reduces acute pressure on weight bearing areas of the front feet. Furthermore the sawdust may dry slurry on the claw's surface, reducing the risk of infection and chemical erosion. It could be argued that animals with more lesions are standing for less time in the cubicles because of them. If lesions are affecting standing behaviour why were there no other correlations with standing behaviours outside the cubicle or ultimately associated with higher lying times - a behaviour that increases if the cow is lame?. At present it is uncertain if there is any pain associated with subclinical lesions therefore, for this study, consideration will be taken that lameness could affect behaviour and vice versa.

Some studies have suggested that standing half in the cubicle would place increased weight on the hindclaws and increase the risk of lameness in the hind outer claws. This theory is not validated by this study, as the majority of cubicle standing behaviour was performed half in the cubicle area and is negatively associated with the amount of subclinical lesions in the hind claws. Weight displacement in this situation was possibly insufficient to significantly influence lesion development.

When aspects of both standing and lying behaviour were combined to obtain a value for total cubicle occupation, this measure was strongly correlated with a reduction in front foot and hind outer claw lesions during examination 1. Animals that occupied cubicles for a larger portion of their daily activity budget, had a lower lesion score. The significant negative correlation between these variables was only seen during examination 1: lesions were at a particularly low level of incidence at this time. There was no significant correlation between cubicle occupation and lesions in any other examination, notably during exam periods 4, 5, and 6 when lesions were at their highest level. This suggests that overall cubicle occupation through the housing period had very minor effects upon lesion development but certain types of cubicle behaviour such as standing had a greater influence. It is difficult to determine cause and effect between behaviour and lesions. Some indication is given when cubicle standing behaviour in the early housing period, when there are few lesions, is compared with that same behaviour in the late housing period when lesions were abundant. The mean time spent standing in the cubicles was calculated for all autumn calvers over the watches 2, 3, 4 (early housing) and 10,11,12 (late housing). Autumn calvers were chosen because the calving pattern was compact compared to the spring calvers. A simple paired t-test showed that there was no significant difference in cubicle standing behaviour between these two values (early housing cubicle standing =4.8 % of scans, late housing= 5.4 %, $t=1.23$, $p>0.05$), although cubicle standing was higher in the three late housing watches. This strongly suggests that because cubicle standing behaviour did not decrease significantly over the housing period during the rise in lesions, it suggests that behaviour is possibly affecting the development of these subclinical lesions.

Lying behaviour had only minor effects on lesion development across the majority of the precalving and post-calving examination periods. In period 5 lying time was negatively correlated with front inner score. Logically if an animal is lying for a longer period of time then claws are not being loaded and eroded on concrete and the risk of increasing lesion severity will be reduced. However lying time was only correlated with front feet lesions, a minor area in terms of total lesion score compared to the hindfeet. This partly explains why lying time was not strongly correlated with total lesion score. Therefore the hypothesis that lying time itself is influential in the development of lameness (e.g. Colam-Ainsworth *et al*, 1989) remains largely unsupported by this study. In contrast, if the lesions had effects on behaviour, then measurable changes in lying times would have been expected, particularly at 2-3 months post calving (peak lesion incidence). Throughout this study, lying behaviour had no significant association with the majority of the lesion measures.

The infectious diseases of the foot such as heel erosion and dermatitis were variably correlated with various behavioural parameters. In the precalving period standing ruminating in the passageway was positively correlated with the incidence of IDD. However post-calving, in examinations 4 and 5, standing ruminating both in the passage and cubicle were negatively correlated with heel erosion, DD and IDD. The relationship between infectious hoof diseases and behaviour possibly reflects the method of disease development that is heavily influenced by environmental factors such as presence and amount of slurry exposure. Factor analysis indicated that cubicle orientated standing behaviour appeared to confer a reduced risk of developing infectious and erosive hoof diseases compared with passageway standing behaviour. I would speculate that it is a combination of standing on slats and placing the front feet on sawdust that is largely responsible for the reduced risk. Sawdust possibly helped to remove the focus of slurry and other infectious organic matter that gathers in the interdigital space. Generally, sawdust is displaced from the cubicle area every time a cow rises, this material is deposited on the adjacent slatted surface where it may have similar benefits for the hindfeet as it seems to do for the front feet. Furthermore when standing predominately half in a cubicle, the hind claws are placed upon the slatted area where displaced sawdust from the cubicle regularly falls.

The correlations between lesions at one examination and behaviour during the previous examination did not show many significant relationships. The behaviour of animals in period 3, i.e. at calving had a significant effect upon lesions in examination 4, when peak lesion expression occurred. Standing inactive in the passage way was associated with later increased hindfoot and heel erosion score.

By standing on concrete the animal may be increasing the risk of developing lesions but the effect only occurs at or around calving. This suggests that at other times, increased standing on concrete is not sufficient to affect lesion development. At calving however, the interaction of behaviour and the other stresses around this period were additive, resulting in a detectable interaction between standing and lesion score.

6.4.2 Factor scores

The analysis of the relationship between factor score and lesions proved more enlightening. The factor scores provide an insight into the relationship between the various behavioural states expressed. Factor scores are based on behavioural data from watches 5 to 12. The early watches will have behavioural observations that coincided with a period where few lesions were seen (especially for the spring calvers) whilst the later watches would have been conducted at a time when more lesions were seen within the hoof. The first factor represents the behaviours that account for the largest proportion of variance within the sample group. Factor 1 was correlated with heel erosion and the infectious foot diseases. As this factor loaded for standing within the cubicle, it could be seen that performing this behaviour prevented, or at least decreased, the risk of contracting these diseases by exposing them to less slurry combined with the beneficial effect of sawdust contact.

The second factor mainly represents standing behaviour not associated with the cubicle but had no detectable effect on lesion score. This emphasises that standing on concrete over the post-calving period did not affect hoof health.

Feeding time and lying inactive are represented by loading heavily in factor 3. This factor was strongly positively correlated with lesion scores in the front feet, particularly front inner claw lesions. Feeding behaviour loads positively for this factor, therefore animals that fed for longer had a more severe lesion score in the front feet. The posture of the animal at the feed face may be responsible for this effect in explaining why only the front feet are involved in this relationship. As they feed, cows have to lower their heads or stretch to obtain the choicest forage. To do this they splay their front legs placing increased stress on the front inner claws (Cermak, 1987). Therefore cows which feed for the longest periods of time place more stress on the front feet which in turn lead to increases in lesion score in the front but not the hind claws.

The effect of behaviour on lesion development at the individual level is far from clear. Cause and effect is not easily determinable from this study and assumptions have been made. Behaviour obviously has stronger influences at specific times in relation to the calving and housing period. The utilisation of the cubicle area to engage in various standing behaviours is more important than lying behaviour, possibly because overall lying time pre calving and post peak yield was comparable to times on pasture (housing lying time= 10.8h sem 0.9 pasture =11.1h sem 0.2. unpublished data). There was also a strong relationship between behaviour and infectious foot diseases. In summary it appears that behaviour is a minor factor in the development of lesions but has a greater influence on infectious foot diseases, which in some systems constitute a far more serious problem.

7 Relationship between hoof lesions and lying-down behaviour in cubicles

7.1 Introduction

On pasture cows are able to move from standing to lying postures with ease. In contrast, during the housing period the dairy animal is expected to lie within a defined area. This lying space which is much smaller than she is accustomed to on pasture, which in addition, does not provide the opportunity to lie laterally recumbent. To utilise the cubicle lying area effectively, a cow must position her feet correctly before attempting to lie (Cermak, 1987) and even so may make a number of attempts before finally succeeding. Preceding lying, considerable time is invested in investigating the cubicle area (Gustafson *et al,* 1988; Krohn & Munksgaard, 1993) which may indicate the difficulty this task presents for the animal. There are also additional complications during rising, as inadequate space may overload joints and cause difficulty in rising (Cermak, 1987).

Findings from a pilot study conducted in the first year showed that locomotion score was not strongly correlated with individual sub-clinical lesion scores for trial animals. It is entirely possible that an animal with a clinically developed disease will not show subsequent aberrant gait when walking along a smooth surface due to the fact that the animal is accustomed to distributing weight on the claw to minimise pain. Therefore it was decided to study lying-down behaviour.

It was hypothesised that during the transition between standing and lying in a cubicle, cows would be unable to distribute weight evenly resulting in a higher level of pain for cows with developed claw lesions. This would be partly due to the movements involved in lying in a confined space and partly due to the uneven distribution of the bedding material on the lying surface. As a result, cows with more severe lesions would show differences when lying down compared to cows possessing less severe lesions.

Cows with more severe lesions might lie down more quickly than normal animals to shorten the period of pain encountered, or make more attempts or lie more slowly and deliberately, to prevent pain arising. In addition, cows with severe lesions might show additional differences during rising from the lying position.

To investigate this hypothesis the transitional lying behaviour of lactating cows was observed in detail together with an assessment of lesions and other diseases in the hooves of these animals

7.2 Materials and methods

7.2.1 Animals

The animals used in this chapter were also involved in the in-depth lameness examination study. The feet of these animals were routinely examined in relation to the housing and calving period. For further details see chapters 2 and 5. In total, 415 observations were made on 52 animals divided between the two units. For this analysis only the animals with 5 or more recorded lying bout observations were used, consequently this reduced the sample size to 45 individuals with an average of 8.7 records each. Individuals were plainly marked with a painted number on their flanks and consequently were easily identified from the videos.

All animals had calved and were in the milking section of the herd in each unit. For a more detailed description of animals see chapter 2.

7.2.2 Observations

The observations were made using seven consecutive 24 hour video recordings of the cubicle house during year 2 of the trial. Unit 1 was recorded in the period 22/3/96 to 28/3/96, unit 2 was recorded from 30/3/96 to 6/4/96. Three cameras were positioned so that 40 out of the 70 available cubicles were observed. The cubicles selected were those in areas that were predominantly used by trial animals. Images from each camera fed into a video junction box so that the 3 camera fields could be recorded onto 1 screen image. As not all of the cubicles could be covered by the camera's field of vision there was a chance that that some animals would not be recorded.

Three low light, wide angle video cameras were used with the video output being fed through a split screen switchbox (Panasonic quad unit WJ-410) into a time lapse video recorder (model Ikegami WVP-100E). The resolution of 3 frames/sec enabled behaviour to be timed to the nearest second.

Every instance of lying down by a trial cow was analysed for the following parameters

<u>Preparatory phase-</u> (Selection to initial lying) time from selecting a cubicle by placing both front feet in the cubicle area and lowering head under the headrail to the initiation of the first lowering leg movements. In some instances the cow would just stand in the cubicle with its head over the headrail. This behaviour was not

recorded. The initiation of the recorded behaviour had to include the head being placed under the headrail. The distance a cow moved forward under the headrail would possibly indicate how much difficulty she would have manoeuvring from the lying to the standing position. This period is often characteristically accompanied by a side to side pendulum motion of the lowered head when standing.

Lying phase- time from first lowering of forelegs and haunches to become fully recumbent.

Total time to lie- sum of preparatory and lying phases of lying down behaviour.

Time to rise- time to get out of a recumbent position to fully standing.

Length of lying bout- total time from becoming recumbent to rising again.

Time of day for behaviour.

7.2.3 Lesion examination

All animals' feet were routinely examined as they constituted part of a larger longitudinal study on the development of lameness (see chapter 2, 5, 6). For analysis in this experiment, the last examination prior to the video observation period was selected.

7.2.4 Statistical analysis

The effect of treatment and calving season was investigated using general linear model 2 way ANOVA. The relationship between lesions and behavioural parameters was analysed using Spearman rank correlations. For consistency with other chapters, the level of significance was set at 1%.

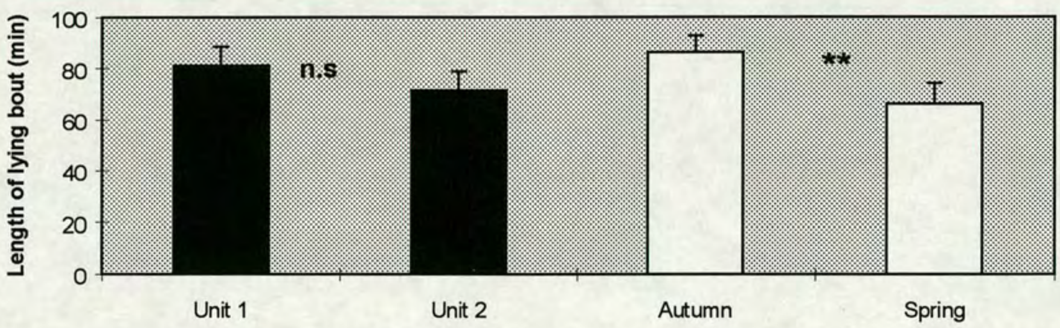
7.3 Results

There was considerable variation between animals, calving group and treatment in the lying down behavioural parameters recorded.

Length of lying bout

There was no significant difference between units 1 and 2 in terms of mean lying bout length, but there was considerable difference between calving season, spring calvers having significantly shorter lying bouts than autumn calvers ($p<0.01$) (Fig 7.1).

Fig 7.1 Mean length of lying bout between treatments and calving season



There were no significant effects of treatment or calving season on the mean time of either the preparatory or lying phases when an animal lies in a cubicle ($p>0.05$) (table 7.1). The preparatory phase was longer than the lying phase in nearly every case.

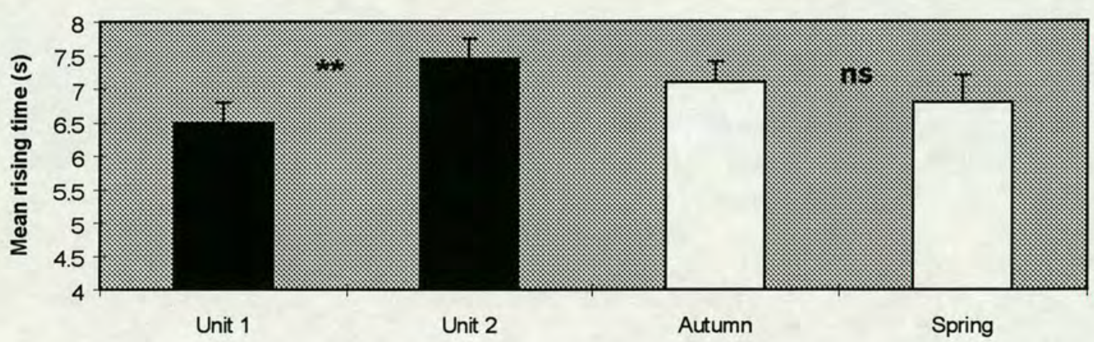
Table 7.1 Effect of treatment and calving season on the preparatory and lying phases of lying down behaviour

	Treatment			Calving Season		
	Unit 1	Unit 2	p	Autumn	Spring	p
Preparatory Phase (s)	9.7 (0.8)	9.3 (0.8)	0.61	9.1 (0.7)	9.8 (1.0)	0.34
Lying Phase (s)	4.5 (0.2)	4.6 (0.2)	0.36	4.5 (0.2)	4.7 (0.2)	0.08

(Standard errors are shown in brackets)

There were significant treatment differences (p<0.01) in the mean time to rise, unit 1 animals taking significantly less time to raise themselves into a standing position. There was no significant effect of calving season on mean time to rise (Fig 7.2).

Fig 7.2 Effect of treatment and calving season on mean rising time.



Spearman rank correlations were performed to determine the relationship between lesions and lying down behaviour. Front, hind and total lesion scores were not significantly correlated with any aspect of transitional lying behaviour (P>0.05). There was a significant relationship between infectious foot diseases and lying behaviour. Digital dermatitis was positively correlated with length of lying bout and negatively with the lying phase. Interdigital dermatitis was negatively correlated with the preparatory and lying phase of the lying down movement together with total time to lie (Table 7.2).

Table 7.2 Spearman rank correlations between hoof lesions and transitional lying behaviour

	Preparatory Phase	Lying phase	Total time to lie	Time to rise	Length of lying bout
Front inner claw score	-	-	-	+	+
Front foot total score	-	-	-	-	-
Hind outer score	-	+	-	+	-
Hind feet total score	-	+	-	+	-
Total lesion score	-	-	-	-	-
Heel erosion score	-	-	-	+	+
DD score	-	**-0.31***	-	+	**0.34***
IDD score	**-0.36***	**-0.39****	**-0.42****	+	+

(*= p<0.05; **= p<0.01)

7.4 Discussion

7.4.1 Length of lying bout

The length of the lying bout in this study averaged 76 min across all animals. This was comparable to bouts described by Singh *et al* (1993a) of 71 min and by Krohn & Munksgaard (1993) of 62 min for animals in cubicles and in deep litter respectively. The bout lengths in this study are well below those for tie stalled cows that lie for over 2 hours on average (Krohn & Munksgaard, 1993), presumably because they do not have to get up and search for feed at the feed face. Furthermore tie stalled cows are unlikely to be disturbed by herdmates as the level of social interaction is greatly reduced.

Spring calving animals had significantly shorter lying bouts than autumn calving animals (66 vs. 86min). The observations were made during early spring/late winter, at a time when the spring calvers had only recently begun lactation and consequently were either at or approaching peak yield. This increased yield would be expected to place increasing demand on the spring calving animals, however there was no difference in feeding time between autumn and spring animals. The spring calvers may have made more frequent trips to the feed face at the expense of reducing lying bout length relative to autumn calvers.

7.4.2 Preparatory and lying phases

There was no significant effect of treatment and calving season upon the preparatory and lying phases of transitional lying behaviour. However there were considerable individual differences for these behavioural measures. The preparatory phase on average did not last longer than 10 seconds, considerably shorter than values of 47, 95 and 147 seconds and above reported by Krohn & Munksgaard (1993) for cows on pasture, deep bedding and in tie stalls respectively.

Similar differences were seen with the lying phase as cows in this experiment seem to be able to lie a lot faster than reported values by Krohn & Munksgaard (1993): 4.6 vs. 10.0. In summary, cows in this experimental situation did not expend much time in selecting and lying within a cubicle; possibly they were more agile or more skilled in utilising the cubicle lying area. Cubicle sizes in the above study by Krohn *et al* were comparable to cubicle dimensions in this study, and selection obviously appears to be of minor importance for these cows. In addition, the above study by Krohn & Munksgaard, reported that animals made numerous attempts to lie whereas most animals in this study lay on the first attempt. In fact during the 415 separate observations, cows making two or more attempts to lie was only recorded in 7 instances. This may indicate the animals' motivation to lie in this experimental and management situation was stronger than the motivation to select a lying area.

7.4.3 Time to rise

Treatment had a significant effect upon time to rise as unit 1 animals got up significantly faster than unit 2 animals. This may reflect the increased agility of unit 1 animals partly due to their lower liveweight and condition and partly due to benefits gained through increased activity or increased exercise making the joints more mobile (Herlin, 1994). Alternatively, unit 1 animals being of lower liveweight and condition may have been less hampered by the physical constraints of the cubicle head and side rails in comparison to unit 2 animals, which were larger (mean postcalving liveweight unit 1= 578 Kg, unit 2=608 Kg). Time to rise was comparable with a previous study by Gustafson (1993) where exercised tie stall cows took less than 10 seconds to rise from the lying position.

7.4.4 Relationship between lesions and transitional lying behaviour

There were no significant correlations between subclinical claw horn lesion scores and any aspect of lying down behaviour. The hypothesis that cows with higher lesion scores would show differences in transitional lying behaviour from cows with lower scores was therefore not supported.

Infectious foot diseases, namely digital and interdigital dermatitis (DD & IDD), were significantly correlated with transitional lying behaviour. Digital dermatitis score was positively correlated with the length of the lying bout, which suggests effort being made by the afflicted animal to reduce the pain resulting from this infection. Both DD and IDD were negatively correlated with the lying phase and in addition IDD was negatively correlated with the search phase and overall time to lie. This provides further evidence that infectious foot diseases are painful for the animal, in particular when trying to lie within the enclosed cubicle space. To reduce the duration and perhaps the intensity of this pain, animals with high infectious disease scores lay down faster.

In conclusion, the evidence suggests that infectious foot disease was more painful than subclinical claw horn disruption disease for animals attempting to lie down.

8 Relationship between subclinical lesions, locomotion and other behaviours at feeding

8.1 Introduction

The incidence and level of aggressive disputes rise during confinement (Miller & Wood-Gush, 1991; Galindo & Broom, 1993), due to crowding of animals and increased head to head confrontations as animals move along passageways. Subordinate animals were less able to signal submission by escape behaviour (Arave & Albright, 1981), leading to confrontations, which may in turn have caused damage to the feet by traumatic shearing injuries, or exacerbate the severity of lesions already present. At pasture, food is widely dispersed making it impractical for cattle to defend it as a resource. In contrast during housing, feed is offered in a limited space, resulting in increased competition and disputes over access to this feed (Metz & Weirenga, 1987).

O'Connell *et al* (1989) showed that peak aggression and activity coincided with the initial provision of fresh silage during the morning. At Acrehead, unit 1, being on the lower plane of nutrition is highly food motivated. When initially fed in the morning, there was an intense feeding period, the majority of the herd is either feeding or attempting to feed, compared to unit 2 where a much smaller proportion of the herd feeds when silage is initially provided. Individual animals are highly active, walking to find vacant feed spaces, displacing animals from the feed area and often being displaced themselves. A high amount of locomotory and agonistic behaviour is representative of such a feeding period (Arave & Albright, 1981). Miller & Wood-

Gush (1991) found that over 65% of all agonistic interactions occur at or around the feed area.

An increased walking distance on concrete and traumatic damage caused by slipping on concrete are risk factors associated with lameness (Kempens & Boxberger, 1987). Actual daily walking distances are small during housing compared to those on pasture, furthermore there is considerable variation between individuals within the herd (Phillips & Schofield, 1994). Differences at the individual level reflect social status or variability in expression of patrolling and exploratory behaviour. Locomotory behaviour is related to factors associated with feeding, such as composition of food, bulkiness, available feeding space, incidence of confrontation and timing of feed provision (Kempens & Boxberger, 1987; Zeeb, 1987). Cows with a lower feeding bout frequency expressed lower levels of locomotion (Zeeb, 1987), indicating that feeding behaviour is important for the level of locomotion seen during housing.

The study aimed to assess the amount of confrontation an animal received or initiated, and also the level of activity an individual expressed during the initial feeding hour. The relationship between activity, social and aggressive interaction, and the incidence of hoof lesions was investigated.

Although aggressive disputes occur over a number of resources and in a wide range of specific housing conditions, for the purposes of this study, attention was focused upon the activity and interactions associated with the initial morning feeding period. This was a specific time of day singled out in the literature and from earlier observations of the herd, for its high associated levels of activity, locomotion and aggressive disputes. Individuals express different patterns of behaviour during the feeding hour in terms of both general behaviour and social or antagonistic behaviour. Individuals that are more active during the initial feeding "rush", place increased stresses on the hooves by walking further and increasing shearing forces by performing sharp turns in confined spaces. Hoof injuries are often associated with slips and falls and such mechanical damage has been related to competitive social interactions (Potter & Broom, 1990). It would be reasonable to hypothesise that animals that are the focus of high levels of aggressive interactions, or those expressing increased locomotory behaviour, will have hooves containing more lesions. The locomotory activity expressed during the initial feeding hour may not be indicative of the overall daily mobility. Therefore to obtain a relative baseline of locomotory activity, pedometers were used to measure the number of steps made in 24 hours as a means of measuring daily activity.

8.2 Methods

8.2.1 Design

20 animals were randomly assigned to 4 blocks of 5 animals. Each block was observed on 3 consecutive mornings for 1 hour, behavioural observations were initiated when the feed was placed along the feed face. Each animal was focal sampled for 10 minutes. It was assumed that the behaviour expressed at the start of the feeding period might differ from behaviour at the end of feeding, therefore the feeding /observation hour was divided into 3 observation periods:-

Period 1- initial 20 minutes

Period 2- middle 20 minutes

Period 3- final 20 minutes

Observations on each of the five animals in the block were balanced over the 3 consecutive mornings, so that each animal was observed once in each of the three periods to account for any differences that may have occurred over the feeding hour.

8.2.2 Animals

During February 1997, 20 animals were selected from unit 1, the low input herd (Table 8.1). The animals were selected on the basis that they were not lame as defined by a locomotion score of under 2.5 before the start of the trial. For this reason the animals were taken from the first to third parity as these groups provided the largest numbers of non lame animals. Selected animals within each parity were balanced between autumn and spring calving season. This herd was chosen as it fed for longer in the years 95/96 and lost more weight and condition during those years. All animals were housed in the same building and were lactating at the time of study. Herd size consisted of 70 individuals. They had been housed for a minimum of 3 months and were 3-5 months into lactation.

Table 8.1 Animal information

	Heifers	2nd parity cows	3rd parity cows
Number of animals	10	5	5
Days into lactation (mean)	119	152	133
Initial postcalving weight (kg)	479	583	591
Initial postcalving condition	2.3	2.3	2.8

Animals were identified within the herd by means of freeze brands, painted numbers and plastic collars. All animals were locomotion scored at the start of the experiment to see if any were lame - no animal scored over 3 therefore no animal was considered lame at the start of the trial.

8.2.3 Housing

Animals were loose housed in a standard cubicle building. The construction consisted of a solid floored feed passage with individual feed spaces whilst the cubicle passage was slatted. The cubicles were of Newton Rigg design. For more information see chapter 2 section 2.4. The feeding facilities had 75 feed spaces for 70 animals giving a space: cow ratio of just over 1:1.

8.2.4 Diets

The diets differed for this trial because in 1996-97 alternative forages were included in the diet. The new ration was based on a combination of home-grown forages: grass clover silage, fermented wholecrop cereals and fodder beet (Table 8.2). Fresh milkers received 2kg/day dairy concentrate fed in the parlour, whilst stale milkers received 0-1 kg/day. Observation showed that cows preferentially consumed the fodder beet before feeding on the silage. Feed was provided mid morning, approximately 5 hours after milking.

Table 8.2 Composition of forage mix (kg\head\day)

	Fresh weight	Dry matter weight
Grass silage	24	6.2
Wholecrop	9	3.1
Fodder beet	20	3.5
Supergrains	8	2

8.2.5 Behavioural observation

Animals were focal sampled for 10 minutes each. Data was collected on a hand held PSION organiser pocket computer using *Observer 3.0* (®Noldus Info. Tech.) as an event recording package.

General behaviour categories

General behaviours were grouped into the following categories

BEHAVIOUR	DESCRIPTION
Walking	Cow walking around passages
Standing inactive	Cow standing inactive in feed or cubicle passages not engaged in any interactive or feeding behaviour
Stand ruminate	Cow ruminating in either the feed or cubicle passage

BEHAVIOUR	DESCRIPTION
Stand feed	Cow positioned with head through feed barrier chewing or nosing food
Stand drinking	Cow at water trough actively drinking
Fight	Cow engaged in direct head to head or head to body conflict with another animal, must physically contact one another
Standing misc.	Cow standing in feed or cubicle passage grooming, rubbing against objects or engaged in oestrous behaviour

Turns / slips

Any turns made during the observation period whilst walking or standing in one location were noted. Turns were categorised by separating into classes, basing the definition as follows:- turns through 90°, 180°, 270° and 360°.

The number of slips made by the animal, defined by a sudden compensatory movement to preserve balance whilst walking or standing was recorded. Slips were described simply using front or hindfeet divisions.

Agonistic behaviour

i)Displacements

Displacements from the feed face due to threats, butts or shoves from another cow were recorded. The displacing animals' status was also recorded, most particularly it's age and estimated weight (greater or less). Animals leaving the feed face of their own free will were also recorded.

ii) Threats

The number of threats made in each observation period were recorded. A threat was defined as a lowering of the head and orientating it so that is was at 90° to another animal. This may also be accompanied by a headtoss directed towards the threatened individual (based on Miller & Wood-Gush,1991; Phillips 1993). The status of the threatened animal was roughly assessed as before. In conjunction with the number of threats made, the number of threats received was measured. The status of the threatening animal was arbitrarily recorded.

8.2.6 Daily locomotory activity measures

Relative measures of daily activity were obtained through the use of digital pedometers. These measurements could then be compared with the measure of walking and other activity measures during the feeding hour. Studies of activity using pedometers have mostly used them as a relative measure of locomotion in cattle (Vanvliet & Vaneerdenburg, 1996; Maatje *et al*, 1997).

Digital pedometers that recorded individual steps (Brainwalker electronic pedometer ® Fitpro) were attached to the right hind leg of all animals on trial (Fig 8.1). These instruments proved to be alignment sensitive, and care was taken to ensure that the pedometer was held in as close to the vertical plane as possible when the animal was at rest. The pedometers were waterproofed and sufficiently padded, firstly to protect them from damage, and secondly to allow maximum comfort to the cow. The pedometers were secured in place using cotton bandages and plastic gaffer tape that also prevented the padding from moving and the pedometer slipping out of alignment.

Pedometers were attached following afternoon milking, and left on for approximately 24h before being removed at afternoon milking the next day. Three recordings of the number of steps per 24h were made on non consecutive days so that a mean value for steps per day could be calculated from the three readings.

Fig 8.1 Attachment of Pedometers

8.2.7 Hoof examination

All animals were examined 1-4 weeks post trial using the techniques described in chapter 2, section 2.8. This involved recording all lesions within the claws and extent of heel erosion and infectious diseases using various objective scoring systems.

8.2.8 Statistical analysis

Since the data for each behaviour was not normally distributed, the differences between heifers and cows were analysed using Kruskal-Wallis. Factor Analysis was performed on the total duration of behaviours and frequencies of threat behaviours across all periods, to determine the association between the various parameters recorded. The analysis would also provide factor scores to indicate which animals, if any, were clearly different from the rest of the group. Factor scores for 3 factors were generated for each animal, based on scores for each of the behaviours. To determine the relationship between the behavioural measures and lesions, Spearman rank correlations were performed. Due to the large number of correlations, the level of significance was set at the 1% level.

8.3 Results

8.3.1 General behaviour

Walking

There was no significant difference in frequency of walking or walking duration between heifers and cows (Tables 8.3 and 8.4).

Table 8.3 Median frequency of walking bouts between heifers and cows (bouts per 30 minutes of observations)

	Median	Ave. Rank	p
Heifers	5.0	12.3	
Cows	2.0	8.7	0.17

Table 8.4 Comparison of total walking duration (s) between heifers and cows over the 30 minutes of observation

	Median	Ave. Rank	p
Heifers	52.0	33.7	
Cows	26.5	27.3	0. 52

Feeding behaviour

Feeding frequency and duration were not significantly different between heifers and cows (Tables 8.5 and 8.6). However heifers had a higher frequency but a lower duration.

Table 8.5 Median feeding frequencies between heifers and cows (bouts per 30 minutes of observation)

	Median	Ave. Rank	p
Heifers	8.0	11.5	
Cows	7.0	9.5	0.443

Table 8.6 Feeding duration (s) between heifers and cows over the 30 minutes of observation

	Median	Ave. Rank	p
Heifers	1657	8.5	
Cows	1711	1711	0.13

Standing inactive

The median frequency of the time spent standing inactive was not significantly different between heifers or cows (Table 8.7). As with feeding, heifers had a higher frequency.

Table 8.7 Standing inactive frequencies between heifers and cows (bouts per 30 minutes of observation)

	Median	Ave. Rank	p
Heifers	9.5	12.5	
Cows	6.0	8.5	0.13

Heifers spent significantly longer (p=0.02) standing inactive in all periods (Table 8.8).

Table 8.8 Time spent standing inactive (s) between heifers and cows over 30 minutes of observation

	Median	Ave. Rank	p
Heifers	**64**	35.0	
Cows	**36.0**	26.0	**0.02**

8.3.2 Agonistic Behaviour

Displacements from the feed face

There were no significant differences between heifers and cows for number of displacements from the feed face. Heifers were displaced significantly (P<0.01) more frequently than cows (Table 8.9).

Table 8.9 Number of displacements from the feed face received by heifers and cows over 30 minutes of observation

	Median	Ave. Rank	p
Heifers	**6.5**	36.6	
Cows	**3.5**	24.4	**0.003**

The total number of threats an animal made towards another herd animal was significantly different between heifers and cows. Cows made significantly more threats compared to heifers across the feeding hour (p<0.01) (Table 8.10).

Table 8.10 Number of threats made by heifers and cows over 30 minutes of observation

	Median	Ave. Rank	p
Heifers	**7.0**	7.3	
Cows	**17.0**	13.7	**0.01**

There was no significant difference in the number of threats received between heifers and cows (Table 8.11).

Table 8.11 Comparison of median number of threats received between heifers and cows over 30 minutes of observation

	Median	Ave. Rank	p
Heifers	16.0	10.4	
Cows	14.0	10.7	0.91

8.3.3 Factor analysis of behaviour

Six behavioural measures of agonistic and maintenance behaviour were used in the factor analysis. They were as follows:-

Total number of displacements

Total number of threats made towards another animal

Total number of threats received

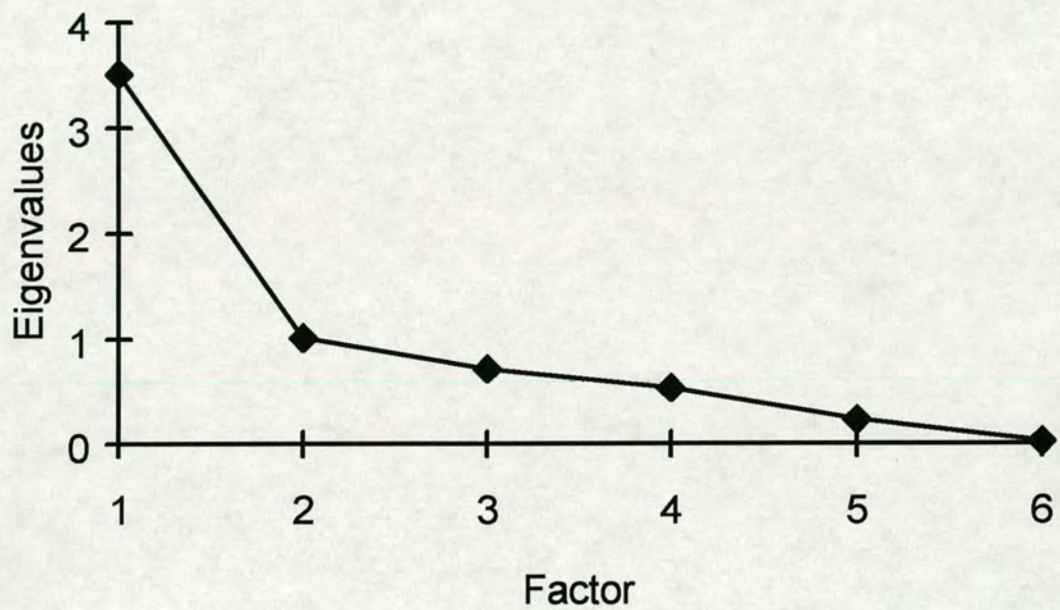
Feeding duration

Standing inactive duration

Walking duration

An initial scree plot of the eigenvalues for each factor revealed 2 factors with eigenvalues of 1 or more (Fig 8.2). The first three factors accounted for approximately 90% of the variance.

Fig 8.2 Scree plot of eigenvalues for each factor



From the rotated factor loadings for each variable, Factor 1 (eigenvalue 3.51) accounts for 51% of the total variance. The variables that show high loadings in this factor i.e. over $\pm$0.5 were total displacements, feed duration, walking and standing inactive duration (Table 8.12). This factor was termed **displacement/stand**.

Factor 2 (eigenvalue 1.01) accounts for 18% of the variance and has high loadings for total numbers of threats made (Table 8.12). This factor was termed **threats made**.

The third factor had an eigenvalue of below 1 (0.71, 16% of variance) but accounted for a large proportion of the of the variance for the behavioural variable - total number of threats received. Factor 3 was termed **threats received** (Table 8.12).

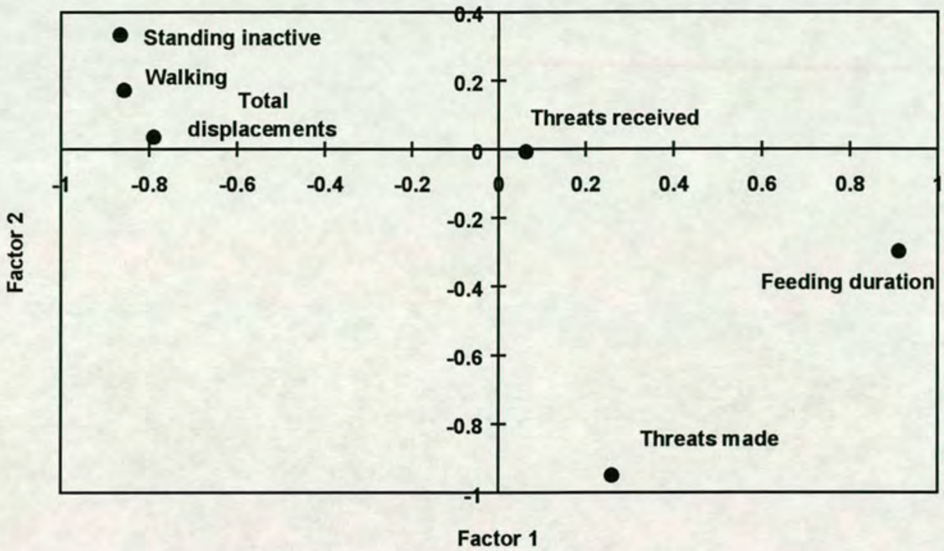
Table 8.12 Factor loadings for each variable in the 3 factors formed after varimax rotation analysis

Variable	Factor 1	Factor 2	Factor 3
Total displacements	**-0.79**	0.036	0.104
Total number of threats made	0.26	**-0.950**	-0.007
Total number of threats received	0.064	-0.007	**-0.996**
Feeding duration	**0.912**	-0.298	-0.015
Standing idling duration	**-0.865**	0.333	0.007
Walking duration	**-0.856**	0.172	0.037
% variance	51	18	16

(Numbers in bold indicate those loadings which are strongly influencing that factor)

By plotting the factor loadings we see that feeding duration acts opposingly to the 3 factors of standing inactive, walking and total displacements (Fig 8.3).

Fig 8.3 Plot of factor 1 against factor 2 for the behavioural variables



Individual animal factor scores were generated for each animal based on the loadings for each of the variables estimated. The behavioural variables measured can be used to calculate a composite factor score for each animal for each of the 3 factors. Differences between 1st, 2nd and 3rd parity animals in individual factor scores were analysed using a general linear model ANOVA. The relationship between the factor scores for each animal and the pedometer readings and various aspects of the lesion score can be investigated using Spearman rank correlations.

Parity had significant effect on factor 2 but on no other factor. Factor 2 was essentially the number of threats an animal made, third parity animals made more threats than first parity animals (Table 8.13).

Table 8.13 Effect of Parity on factor scores

	Factor 1 Displace/stand		Factor 2 Threats made		Factor 3 Threats received	
Parity	Mean	sem	Mean	sem	Mean	sem
first	-0.295	0.372	**0.467**[b]	0.185	0.016	0.280
second	0.302	0.310	**0.022**[ab]	0.383	0.096	0.696
third	0.287	0.381	**-0.911**[a]	0.577	-0.127	0.328

(Means with different superscripts are significantly different p<0.05. Means with no superscript are not significantly different within that factor)

Spearman rank correlations were used to investigate the relationship between the mean pedometer readings, number of fights and slips with the factor scores for each animal. There was no significant correlation between these variable and the factor scores (p>0.05).

8.3.4 Relationship between general behaviour, social behaviour, daily step recordings and lesions

Only one correlation achieved the 1% significance level, showing that displacements from the feed face were positively associated with front foot score. Due to the large number of correlations there is a high likelihood that this correlation could be due to chance. Furthermore the majority of the correlations did not achieve the 5% significance level. Therefore it is reasonable to assume that there is no discernible relationship between behaviour expressed at feeding, step recordings and lesion score in this study (table 8.15).

Spearman rank correlations between factor score and lesion score did not show any significant relationships (P>0.05) across all categories of lesion.

Table 8.15 Spearman rank correlations between behavioural and lesion parameters

	Front inner score	Front foot total score	Hind outer score	Hind foot total score	Total lesion score	Heel erosion score	DD score	IDD score
Feeding duration	-	-	-	-	-	+	-	-
Feeding bout frequency	+	+	-	+	+	-	+	+
Standing inactive duration	-	+	+	+	+	-	+	+
Standing inactive frequency	+	+	-	-	+	-	+	+
Walking duration	-	+	-	+	-	-	+	+
Walking frequency	-	+	-	-	-	-	+	+
Frequency of 90° turns	-	+	-	-	-	-	+	-
Frequency of 180° turns	-	-	-	-	-	-	-	-
Frequency of 270° turns	-	-	-	-	-	-	-	-
Displacements by conspecific	+	+	+	+	**0.44•**	+	+	+
Displacements by bigger animal	+	+	+	+	+	-	+	+
Total displacements	+	**0.57***	+	+	+	-	+	+
Frequency of slips	-	+	-	-	-	**-0.52•**	+	+
Mean number of steps/day	+	+	-	-	-	-	+	+

(* Indicates p<0.01, • indicates p<0.05)

8.4 Discussion

There were substantial parity effects upon behaviour both general and agonistic. First parity animals were displaced from the feed face far more often than older animals, resulting in heifers spending significantly more time standing inactive. The factor loadings confirm this. Animals that were displaced more often had a reduced feeding time and an increased standing inactive and walking time. This showed a possible effect of social structure on feeding behaviour. Kempens & Boxberger (1987) reported that feeding bout frequency is influenced by social rank. Dominant high ranking cows spent more time at the feedface or trough (Friend & Polan, 1974), and attacked and displaced herdmates more often especially when feeding space was limited (Metz & Mekking, 1984; Metz & Weirenga, 1987). Heifers being of lower social status, presumably because of their smaller size or inexperience made far less threats towards other individuals than cows. Dominance is related to age and size, older cows are generally more aggressive towards younger cows (Reinhardt & Reinhardt, 1975). The difference between heifers and cows could also be due to the fact that there are many more cows within the herd than heifers, (roughly 3:1) leaving fewer animals of similar size and age for heifers to threaten. This is indicated by the fact that cows made significantly more threats directed at smaller, younger herd animals than do heifers (median number of threats at conspecifics, heifers 5.5, cows=14.5, p=0.04). Therefore heifers are compromised in terms of feeding behaviour by their social status or ease of displacement, which has direct effects on walking and standing inactive behaviour. There were differences between the number of threats made and received. This could partly be explained by the selection of non lame cows which may have been more dominant or more able to express aggressive behaviour.

The factor analysis confirms the interrelationship between displacements, feeding and other behaviours mentioned above. Third parity animals had negative scores, therefore they probably made far more threats towards other animals than first and second parity animals, confirming their higher social status within the herd.

Front foot score was significantly correlated with total displacements from the feed face, and displacements overall were positively associated with all lesions scores. Furthermore, due to the large number of correlations, it is highly likely that this finding may be a relationship that occurred due to chance. The numbers of animals used in this experiment were small, due to the number of non-lame heifers and young cows available for study. To be more conclusive, more experimental subjects would obviously have been desirable. Work conducted by Galindo & Broom (1993) showed that increased displacements are correlated with an increase in walking time and that cows that spend more time walking had a higher incidence of foot disorders. However the animals used by Galindo and Broom had more severe claw horn lesions and included older animals (relative to the animals in this study) that would be more prone to having severe lesions.

There appears to be a very weak relationship between behaviours and social interaction at initial feeding and the total amount of subclinical lesions. Arguably the small sample size and low numbers of observations could be the resultant cause. Another reason could be that the trial animals had all passed the critical 2 months of early lactation which appears to be a formative period in the development of hoof lesions. The effects of any behaviour expressed after this period are probably minor, however behaviour is an additive risk factor together with factors associated with calving.

9 General Discussion

Following discussion of the findings in this study, this chapter will identify areas for future work. Recommendations are also made on how these can be developed into management systems to improve dairy cattle welfare with particular reference to lameness.

The work reported here improved on a number of past studies as the behavioural watches and hoof examinations were co-ordinated and conducted more frequently over the housing period (Bradley *et al*, 1989; Greenough & Vermunt, 1991; Singh, *et al,* 1993a; Leonard *et al*, 1994). These examinations were assembled to allow detailed representations of an individual animal's history during a complete housing/calving period. The extent of the lesions associated with lameness both at the subclinical and clinical level was recorded using methodology that provided an insight into the severity and extent of the disease within the claw horn. Conducting the work in this systems study allowed it to be representative of current, commercial, management practices yet the management was more tightly regulated compared to a conventional farm. This allowed the dietary and husbandry regimes to be rigidly monitored over the housing period. The use of multivariate statistical techniques to generate factor scores based on various behavioural components of the animal's activity, enabled the inter-relationships between lesions and behaviour to be considered in detail at the individual animal level. This novel approach enabled analysis of treatment factor effects without completely ignoring the multifactorial nature of lameness disease.

9.1 Aspects of lameness development

9.1.1 Clinical incidence

Many previous studies have estimated the incidence of clinical lameness in the UK, typically reported as 25% or below per year (Arkins, 1981; Whitaker *et al*, 1983; Collick *et al*, 1989). The incidence at Acrehead was far greater at approximately 37%, being midway between the above and the value of 57% reported by Clarkson *et al* (1993). The figures reported in some previous studies suffer from the inaccuracy associated with the collation of figures derived from veterinary practices, which represent predominantly severe clinical cases. This type of data may not take into account cases of lower severity which are treated on farm by stockmen (Clarkson *et al*, 1993), or it may utilise farm records which are notoriously unreliable (Boyd, 1992). If previously reported incidence figures are underestimates then lameness is an immense problem, and prompt action should be undertaken to evaluate and implement preventative management strategies.

This study illustrated how relatively minor management differences between herds appear to have dramatic effects upon the incidence of clinical cases. However this work is similar to an observational epidemiological study comparing groups of animals either exposed or not exposed to a hypothesised risk factor as opposed to an experiment were it is possible to randomly allocate animals to treatments. As animals could not be randomly assigned to each herd there may have been an intrinsic difference between these two groups of animals which may have contributed to the various differences found. The herds could be said to be similar in terms of genetic merit (same sires used in breeding policy), youngstock rearing, calving pattern, housing and stockmanship but due to various factors such as involuntary and voluntary culling on herd structure they cannot be called "identical". Consideration to the extent of similarity between herds must be made in assessing the differences found. The distribution of disease types at Acrehead showed that the incidence of foul in the foot was significantly higher in the feet of autumn calvers in the high input unit, unit 2, compared to unit 1 (16 vs 3 cases). Incidences of foul are higher in the autumn period (Rowlands *et al*, 1983) and the disease is closely associated with housing due to the cows' close proximity favouring disease transmission (Bergsten, 1997). While both units were housed separately they are milked in the same parlour and use the same walkways when at pasture, therefore it seems likely that initially both herds were challenged with factors associated with this disease, i.e. the infective organism *Fusobacterium necrophorum* and interdigital abrasion. However within unit 1, autumn calving animals experienced a period of extended grazing. This daily grazing period may have been influential as one of the major risk factors for this disease is exposure to contaminative material in moist anaerobic conditions. The brief time at grass may have reduced the risk from these factors by cleaning the feet and allowing air to circulate. The difference cannot absolutely be attributed to extended grazing, but it is highly likely, since risk factors for such infectious diseases are largely dependant on environmental not animal factors. The high level of foul in the foot in the high input group is largely responsible for the higher incidence of lameness lesions found in this herd. Furthermore, the incidences of non-infectious lesions, particularly the overall compilation of "clinical claw horn disruption" (CHD), were similar between units (No of CHD lesions: unit 1= 37, unit 2= 32).

9.1.2 Subjectivity and severity

The fate and significance of subclinical lesions for the dairy animal were not addressed in this study. Lesions occurring in certain areas may have concequences for the future hoof health of the animal. Lesions occurring at the heel sole junction may have had serious repercussive effects in future lactations compared to less significant areas such as the toe or in low weight bearing claws. The scoring system in some way takes into account the severity and extent of the lesion; however, the interpretation of what these actually represent for the individual animal is still the subject of study (Offer *et al*, 1997). Subclinical lesions may not always cause pain.

Unpublished data shows that clinical white line lesions are likely to occur in areas which previously had extensive subclinical lesions. Some lesions found during this study were almost certainly clinical, but caused no signs of lameness in the animal's gait, whereas lesions of identical or lower score in specific positions caused clinical lameness gait signs. The locomotion score system was a measure of an animal's mobility, which probably takes into account how painful conditions were in the claws. In some instances, an animal did not show clinical signs of lameness in terms of locomotion score, but when hoof examination was conducted, a lesion was found, which under other circumstances would have been considered clinical. During such examinations the animals showed considerable discomfort if these particular lesions were touched. The site of a lesion may be just as important as its severity, dependent on how the cow perceives pain or how she is able to compensate for any pain present. For example, 3 large areas of the claw each scoring 2 on the lesion score system may not be as painful as one small deep lesion scoring 6 even though their total scores are identical. The problem of transforming the data realistically to reflect the importance of severe lesions and pain caused for the animal has been discussed by Greenough & Vermunt (1991) and by Leach *et al* (1997) but the debate is by no means resolved. Recent work by Whay *et al* (1997) has shown that lameness reduces the pain threshold and that subclinical lesions were able to influence this threshold. In addition claw horn lesions as opposed to those on the digital and interdigital skin, lowered the nociceptive threshold for a longer period, but that skin lesions caused the largest initial change in response levels.

9.1.3 Calving and housing

The experience of cows moving through the housing/lactation period was critical. Locomotion scores showed that while average scores did not differ markedly, spring calvers had lowest scores over the lactation (mean score= 1.8) whilst autumn calving cows had the highest (mean score= 2.0). Furthermore autumn calvers exhibited more clinical lameness lesions than spring calvers (104 vs 73). It is suggested that this was due to the risks associated with calving and autumn housing, which occurred simultaneously for the autumn calving group. In contrast the spring calving animals were allowed a period of adaptation, being introduced to housing 1- 2 months before calving, therefore reducing the likelihood of lameness associated with the additive risk factor effects of housing and calving. Bazeley & Pinsent (1984) report that there was a reduced incidence of laminitis on farms where animals were introduced to housing some weeks before calving. Many farms, particularly small units, spread their calving season throughout the year whilst larger units increasingly split their herds into autumn and spring calving groups. This enables these farms to optimise milk production in order to maintain consistent output over the entire year. Thus, in general, it is impractical to avoid calving some cows in the autumn.

9.1.4 Parity

Locomotion scores showed that cows had poorer mobility than heifers (mean score 1.9 vs 1.6) suggesting that their locomotion is compromised by the additive damage of successive lactations and possibly by damage caused by previous foot lesions. The increasing risk of developing lameness disease with age has been reported by various authors (Rowlands *et al*, 1983; Enevoldsen *et al*, 1991a, b). On the basis of such studies (Enevoldsen *et al*, 1991a; Peeler *et al*, 1994; Ward & French, 1997) it is argued that reducing the risk for first parity animals in their initial lactation/housing period would reduce the lameness risk for these animals later on in their productive lives. Thus the emphasis should logically be placed on first calving heifers and a management system that reduces their exposure to extreme stresses associated with calving and housing. As it is impossible to remove all of the risk associated with calving, concentrating on housing management is essential. Possible strategies could involve straw yards to reduce risk, reducing the amount of time spent in housing or changing to a summer calving season: a period when the first calving heifers would be at pasture hence their exposure to the deleterious effects of housing would be reduced.

There is also however, a behavioural risk factor which is inversely related to age. Dominant animals have priority for access to feed and lying places compared to subordinates which have more aggression directed towards them and have an increased frequency of displacement from the feed and cubicle areas (Friend & Polan, 1974; Miller & Wood-Gush, 1991). The dominance hierarchy is heavily influenced by age; heifers being smaller and more easily bullied, are largely subordinate to older, larger animals (Reinhardt & Reinhardt, 1975). There has been speculation that increased aggression directed towards subordinates leads to escape behaviour that is potentially damaging to the claws, increasing the risk of lameness for these animals (Bazeley & Pinsent, 1984; Metz & Wierenga, 1987; Potter & Broom, 1987). The study of feed face behaviour and its relationship to hoof lesions (chapter 8) showed that there was no strong link between these two variables. However, sample size and extent of subclinical lesions recorded in this study may not have been sufficient to conclusively dismiss any association. The first parity animals received more direct aggression and were displaced almost twice as often compared to second and third parity animals (Number of feed face displacements/ hour, heifers= 6.5 cows= 3.5). There have been few studies that directly assessed the influence of social behaviour and incidence of lameness. Galindo & Broom (1993) reported that subordinate animals that were displaced more often from cubicles, stood in the passageways for longer and had a higher incidence of clinical lameness. However this is inconclusive, as animals that suffer from clinical disease are less likely to engage in aggressive confrontations due to the pain involved, and will therefore be displaced more frequently compared to animals that are not lame. In the feeding behaviour study (Chapter 8), no animal was recorded as clinically lame, furthermore there was no apparent influence of disease on behaviour and vice versa.

9.1.5 Activity and other behaviours

Treatment appeared to have significant effects on animals' activity budgets particularly regarding the amount of time they spent feeding (% of day spent feeding unit 1= 26%, unit 2=20%). Within the treatment factor there could have been a number of reasons why the low input herd fed for longer, for example the higher long fibre content of the diet. The ration provided for unit 1 was diluted with straw in increasing amounts toward the end of the housing period, and it is at the highest level of straw inclusion that we see the longest feeding times, i.e. watches 12 & 13 (Fig 4.6). The behavioural influences on lameness were dependent on the individual animal's responses to treatment, housing and social factors. Multivariate analysis allowed an investigation into the interrelationship between the major behaviours. Certain behaviours were closely associated, others weakly, within an animal's activity budget, and by using this analysis to generate factor scores it was possible to investigate in detail the relationship between behaviour and lesion incidence. Factor analysis used average behaviours recorded before, during and after the time of peak lesion incidence. Over this period, behaviours did not markedly change between watches within each animal. It is possible therefore that it is overall 24 hour behaviour that influences the level of subclinical lesions in these non-lame animals. The analysis revealed certain behaviours were positively and others negatively linked with the incidences of specific lesions. Standing behaviours that occurred within the cubicle area were associated with improved front foot health, including infectious disease and heel erosion. Standing within the cubicle was possibly a response to overcrowded housing conditions or a strategy developed by individuals either to maximise personal space or to avoid social/rank conflict. Colam-Ainsworth *et al* (1989) stated that excessive standing in the cubicles is a behavioural abnormality and is associated with a higher incidence of laminitis. In a study of group housed pigs by Mendl *et al* (1992), a certain behavioural type was identified which they termed "no success" pigs: these animals never aggressively displaced another pig, were least aggressive and were most inactive. This strategy was adopted by pigs of very low rank to cope with the social environment of group housing without the energy costs and other detrimental effects incurred by contesting aggressive interactions. The cubicle standing behaviours performed by individual cows was a possible strategy to reduce the likelihood of an aggressive interaction, similar to the inactivity of "no success" pigs. Cows may prefer to be uninterrupted when performing certain behaviours such as standing ruminating, a behaviour that can account for about 30% of total rumination time. Furthermore most wild ruminants retire to a place of safety to ruminate (Kilgour & Dalton, 1984). Furthermore aggressive disputes may have been so stressful for the individual it made a conscious effort to avoid these. The cubicle standing behaviour was associated with lower front foot lesion scores, thus an animal adopting such a strategy obtained health benefits, albeit indirectly.

The univariate analysis revealed that front and hind feet differed in their associations with various behaviours. In terms of lesions, a lower score for the front feet was associated with specific behaviours i.e. cubicle behaviours, however these associations were not apparent in the hindfeet. This finding does not appear to have been reported previously in the literature.

Cubicle standing behaviour had the strongest association with reduced incidences of infectious foot diseases and the extent of heel erosion. In this study infectious foot diseases seemed to temporarily cause the animal more problems, at least from the point of lying down, than subclinical claw lesions associated with CHD (chapter 7). In contrast, hind feet lesions were not strongly correlated with the majority of the behaviours. Multivariate analysis revealed that the incidence of hind foot lesions was weakly associated with a reduced feeding time and an increased lying time. The decrease in activity perhaps reduces the risk of lesions or alternatively, animals with more lesions spend more time lying. Other studies have only suggested the relationship between reduced lying times and lameness risk. Colam-Ainsworth *et al* (1989) showed that on farms where animals lay for less time there was an increased incidence of lameness; however, there was a confounding dietary effect of different management systems that may have influenced the risk of lameness. In another study, Singh *et al* (1993a) showed that there was a relationship between lying times and sole lesions. However the study animals were observed during early lactation when initially introduced onto concrete - a time that coincides with peak lesion expression and when lying time would typically be reduced. Leonard *et al* (1996) reduced available cubicles so that the cow/cubicle ratio was almost 2:1; there was a reduction in lying time and an increase in claw horn lesions but the rise in lesions could also be attributed to risks associated with increased aggressive interactions due to the crowding. There is some evidence from the present study that lying time reduction in early lactation may have affected lesion development. However over the entire lactation period these effects appeared minimal (chapter 6). Furthermore animals used in this study may not have been suffering unduly in terms of overall lying times and in reality mean daily lying times over lactation compared favourably with those on pasture (unit 1 housing lying time = 10.2h, pasture lying time = 10.2h; unit 2 housing lying time = 11.6h, pasture lying time = 10.4h).

The small experiment which investigated lying down behaviour showed that infectious foot diseases were possibly more painful than lesions associated with claw horn disruption if the amount of time an animal took to lie can be considered to be an indicator of the animals' comfort. Either animals were able to compensate for pain associated with claw horn disruption by altering foot placement, or these lesions just were not as painful as infectious foot diseases. Other parts of this study showed that overall lying time over housing was weakly associated with infectious lesions. These infectious foot lesions recorded at the time of this study (predominantly interdigital and digital dermatitis) did not cause signs of clinical lameness in terms of locomotion score. Such lesions were not considered severe, relative to cases of foul in the foot recorded in these herds which caused clinical lameness. Alternatively, infectious foot diseases may be painful during any foot movement, regardless of hoof floor placement or gait adaptations, and the animals simply responded to this. Yet it is not this simple as CHD lesions take longer to heal and afflicted animals remain hypersensitive to pain from the lesions long after treatment. Furthermore infectious lesions are often acute and, for the brief period when they are present, seem to cause the highest levels of hypersensitivity to mechanical stimuli (Whay *et al*, 1997). At the time of this study there may have been a small number of animals developing infectious diseases, which, for a transient period, may have affected their behaviour when lying down. Over a longer period these effects would not have been as apparent, e.g. chapter 6. Work by Whay *et al* (1997) has shown the effects of infectious lesions on hypersensitivity to attenuate faster than lesions associated with claw horn disruption.

9.1.6 Diet

Treatment or dietary input in this study caused changes in activity budgets to accommodate the amounts of time an animal spent feeding. The level of subclinical damage in the claws precalving and immediately post-calving was not affected by treatment. This agrees with a recent study by Olsson *et al* (1998) comparing two diets of 60:40 and 40:60 concentrate/forage ratio. However the higher level of concentrate input on unit 2 was associated with an increase in the prevalence later in lactation as median lesion scores for this group did not fall relative to unit 1. There was also a confounding effect in that certain behavioural effects that occurred within unit 1, namely a larger fall in lying time in the initial post-calving period may have altered the level of peak lesions for this group. This would be an indirect effect of treatment on lesion scores and it is difficult to eliminate the potential effect of dietary altered behaviour in this study.

Jackson *et al* (1991) showed that during the early post-calving period, animals fed a diet higher in fibre had reduced energy intakes compared to animals provided a starch based isoenergetic ration. On the other hand, starch based concentrates confer an increased risk of hoof lesions compared to other concentrate types (Kelly & Leaver, 1990), so even here the matter is confounded. Overall, the diet provided for unit 1 animals possibly had detrimental effects in the early post-calving period. The bulky, less energy dense ration, would reduce the energy intake of unit 1 animals relative to unit 2, even though this group spent longer feeding. A reduced energy intake would force the animals to draw on their body reserves and may have caused the increasing incidence of lesions at peak lactation due to the stress associated with catabolism. Metabolic profiles of the herds provided some evidence for this by showing that animals on unit 1 overall had higher blood Non-esterified fatty acid and β-hydroxybutarate (Logue et al, 1999). Conversely increasing the level of high energy concentrate in the diet had opposing effects for hoof health. Some studies have found that higher levels of dietary concentrate inclusion raised the level of clinical claw disorders, presumably mediated through a metabolic route (Peterse *et al*, 1984; Manson & Leaver, 1988a; Spiekers *et al,* 1991). However in the present study, animals on the higher concentrate diet spent significantly less time feeding which would reduce overall standing time outside of the cubicles and possibly increase the available time to lie, thereby reducing the risk of claw lesions. The longer lying time was particularly apparent in early lactation for unit 2 autumn calvers compared to unit 1 animals (watches 2 to 5, Fig 4.16). Total standing time is simply the opposite to total lying time and in this respect unit 2 stood for less time in 10 out of the 13 watches, the difference is small, but presumably attributed to the decreased feeding time. The level of concentrate inclusion in the diet of unit 2 animals, together with the decreased feeding time (and increased lying in early lactation seen for the autumn calvers), resulted in an overall lowering of risk factors associated with subclinical lesion development.

No difference in peak lesion score occurred between treatments therefore each dietary/management treatment led to an equal lesion risk for both units during early lactation. This conflicts with an earlier study by Manson & Leaver (1988b) who reported that diets higher in concentrate caused increased lameness in early lactation. The level of concentrate in their diets however was notably higher and was fed separately compared to concentrate levels fed to unit 2 as a complete mix ration, these additional factors may be responsible for the observed higher lameness incidence in the Manson & Leaver (1988b) study. It is suggested that later into lactation, unit 1 animals were able to increase intake due to changes in rumen flora or capacity and were not compromised in terms of energy intake relative to the early lactation period. The postulated increased intakes are difficult to prove for the in depth study group as there were no facilities or opportunity to record individual intakes. Energy demand would almost certainly be falling during late lactation as milk records of daily yield showed milk production to be declining slowly in this herd. Subsequently the risk factors associated with this diet fell as did the level of lesions found within the claw horn of these animals. A similar effect on prevalence was reported by Manson & Leaver (1989) contrasting high and low concentrate/forage ratio diets. There are of course other factors associated with each herd that confound dietary effects, namely milking and grazing regimes. The thrice daily milking, for example, sustained higher milk production in late lactation (unpublished data) which again may influence the amount of lesions seen at this time.

9.2 Future work

It is an unfortunate fact that system studies are expensive and are generally devised to test a number of farming factors. Thus it is difficult to maintain equilibrium in terms of all the various production parameters for several years in succession. In this thesis, this has led to a problem associated with lack of replication due to changing milking and dietary regimes from years 1 to 2. Any future work would have to address this by either running a 2-3 year experiment keeping management constant, or by having a crossover factorial design. The crossover design is particularly attractive if a suitable set up could be found with adequate numbers of first calving heifers.

The study has also indicated that a more detailed representation of 24 hour activity in the early post-calving period should be undertaken, i.e. 0-8 weeks post-calving. The greatest changes in behaviour occur at this time which are relevant to lesion development. Therefore, weekly 24 hour behavioural recordings would allow a more exact representation of the fall and rise in the length of time specific behaviours were expressed. Once peak lactation is reached the total amounts of specific behaviours stabilise, which would allow watch frequency to be reduced to once a month.

The early management of first calving heifers appears to be a critical period as it may have direct limiting effects on the extent of lameness in future lactations. There are many possible areas that may have direct welfare benefit if thoroughly researched. These include the influence of the early environment and management experienced by heifers, in particular factors such as introduction to concrete, growth rates and aspects of training of in-calf heifers to the cubicles and parlour.

Although treatment affected the level of subclinical lesions and certain behaviours at specific times, no clinical cases occurred in the in-depth study cohorts. Either this is a result of using 1st and 2nd lactation animals which are less likely to become lame or else the management/dietary differences were not sufficient to produce clinical lameness differences in the study groups. The differences between diets would therefore need to be modified either by restricting the low input cohorts or by dramatically increasing the amount of concentrate mix in the diet of high dietary input cohort animals. Realistically however, the diets used in this study represent the extremes of conventional commercial rations, and the justification to do this would have to be based on the future direction of farming practices. Current predictions indicate that a preference toward on-farm derived concentrate substitutes such as maize and other highly fermentable, energy rich, ensilable forages as opposed to rations incorporating high levels of bought in concentrate will occur.

To determine whether the main effects were solely dietary or were a combination of dietary and behavioural effects, a selection of the high input cohort animals could have their available cubicle time restricted in early lactation to lying times equivalent to levels comparable with unit 1. By having a positive control group the exact effects of a reduced early lactation lying time on claw lesions could perhaps be elucidated.

9.3 Application of findings

1) A concerted effort should be made to reduce the various risk factors experienced by animals in their first, and possibly also their second lactation. Summer calving schemes for heifers should be implemented. The bullying and displacement of heifers at the feed face could be reduced by either having a face with barriers that segregated every animal or by managing heifers as a separate

group. Sudden introduction of heifers into an unfamiliar dry cow group adds an additional stress on these animals (Greenough & Vermunt, 1991). Based on this, further improvements could be made if heifers were kept with dry cows precalving so that social dominance and hierarchy positions were established in this relatively low risk period before such low rank animals experience the high risk during early lactation.

2) The bulky high fibre treatment may be too severe a regime for animals during early lactation. Efforts should be made to reduce this stress by providing forage which is highly fermentable such as wholecrop maize or providing additional starch in the form of sugar or fodderbeet. The diet could then be incremented with greater proportions of fibrous grass silage over an adaptation period leading up to peak lactation. Indeed a dietary regime along these lines was implemented in the year following this trial (see chapter 8). Initial analysis of the lameness and production data for this year shows a marked lowering in the incidence of lesions in this herd and an additional improved performance.

3) Cubicle standing behaviour only appeared to benefit the front feet, as cows were only able (in the majority of instances) to place their front feet within the cubicle area due to the headrail restricting forward movement. Removal of the head rail would allow the cow to stand further forward and lie further forward in those cubicles which have had their front wall removed. However there may be problems associated with soiling the back of the cubicles by making such modifications. If the hindfeet could be placed on the sawdusted surface either by making the cubicles longer or by providing a smaller sawdusted area below the cubicle lip then benefits

for overall hoof health might be considerable. There would presumably be a lower risk of infectious foot diseases if cows stood in such modified cubicle conditions.

4) The study indicated that infectious foot lesions are the source of many clinical cases on this farm, and seem to be more painful for the animals compared to CHD. Lesions such as these are some of the easiest to treat and can be controlled by implementation of regular footbathing in the management regime. Such a procedure is most effective when conducted once or twice weekly (Logue, 1994; Kloosterman, 1997). Such a scheme represents a nominal capital investment and is cheap to run in terms of labour costs and improves hoof health dramatically.

The apparent relationship between each of the factors studied and the development of lesions is complex. The interactions between the factors and the response of the individual animals still requires considerable investigation. This work has hopefully identified the most relevant areas, but more importantly, has outlined the basis and direction for future studies.

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Appendix

Dietary information

Table A.1 Proximate analysis of silage. Means of the sward cuts from each year

	Unit 1		Unit 2	
	1994-1995	1995-1996	1994-1995	1995-1996
D.M (g/kg)	317	270	304	310
C.P (g/kg)	161	146	159	137
OM (g/kg)	909	908	917	916
VFA (g/kg)	14	13	16	9
Sugar (g/kg)	81	63	69	118
Digestibility (%)	71.3	73	75	70
ME (MJ/kg)	11.4	11.5	12.1	11.3

Table A.2 Proximate analysis of parlour and blended concentrate

	Blended concentrate	Parlour concentrate
DM (%)	86.47	87.17
CP (%)	22.53	22.10
OM (g/kg/DM)	92.63	63.37
Ca (g/kg/DM)	9.80	12.40
P (g/kg/DM)	7.93	7.87
Mg (g/kg/DM)	4.83	8.10
K (g/kg/DM)	11.83	16.93
Na (g/kg/DM)	3.53	4.03
M/D	12.87	13.03
AHEE (g/kg/DM)	42.37	59.90
NCGD (g/kg/DM)	844.0	822.67

Table A.3 Nutritive values of grainbeet

DM (g/kg)	325
ME (MJ/kg DM)	11.6
CP (g/kg DM)	178
Digestibility	79
EE (g/Kg DM)	64
Ca (g/kg/DM)	3.7
P (g/kg/DM)	2.7
Mg (g/kg/DM)	1.5
Na (g/kg/DM)	1.6
NDF (g/kg/DM)	547

Table A.4 Manufacturers reported nutritive value of fishmeal and Maize gluten

	Fishmeal	Maize gluten
DM (g/kg)	900	900
EE (g/kg DM)	64	38
CP (g/kg DM)	736	262
ME (MJ/kg)	14.5	13.5

Table A.5 Average composition of the Total Mixed Ration (excluding parlour concentrate) over the two years based on group totals of feed provided and estimated for an individual daily intake feeding ration package

	94/95		95/96	
	LI	HO	LI	HO
DMI (kg/day)	19.9	21.2	15.1	20.2
ME (J/kg)	11.9	11.3	11.6	12.0
CP (g/kg DM)	200	184	157	175
Oil (g/kg DM)	55	51	53	55
NDF (g/kg DM)	455	402	469	447
Starch and Sugar (g/kg DM)	103	81	97	162

To place this and other information into context, theoretical diets were formulated using Feedplan- SAC's feed rationing programme. The lactation planning setting was used as this formulates diets on a farm basis using average cow weights and yields to produce basic ration relative to stage of lactation. The average animal weight was set at 550kg and the programme calculates and expected pattern of weight loss and gain over lactation for this weight and a specified yield. The dietary constituents entered into the formulation were altered to equal the proximate analysis values of the actual feeds. The lactation plan was built around a 70 cow herd split equally between autumn and spring calvers in a 7 month housing period starting in October. It was not possible to include the extended grazing period within the formulations for unit 1 as there was no information for intakes during this brief period at pasture.

A.6 Feedbyte predicted ration required by stage of lactation (average herd yield 5250l) for comparison with the ration fed to Unit 1 year 1

Week of lactation	Yield (l/day)	Silage (kg)	Parlour concentrate (kg)	Fishmeal (kg)	Grainbeet (kg)	Maize Gluten (kg)
1-16	26	30.9	1.2	0.8	16.8	6.1
17-32	19	36.6	0.5	0.5	10.8	4.2
33-44	10	37.8	0	0	0	0
dry	0	25.9	0	0	0	0
Estimated ration from group intakes		40	1	0.7	10	4.2

A.7 Feedbyte predicted ration required by stage of lactation (average herd yield 5750l) for comparison with the ration fed to Unit 1 year 2

Week of lactation	Yield (l/day)	Silage (kg)	Parlour concentrate (kg)	Grainbeet (kg)	Straw (kg)
1-16	28	29.0	2.5	18.2	-
17-32	20	35.6	1.0	10.0	-
33-44	11	35.4	0.5	4.0	-
dry	0	27.0	0	0	-
Estimated ration from group intakes		25	2	7.8	5

A.8 Feedbyte predicted daily ration required by stage of lactation (average herd yield 6750l) for comparison with the ration fed to Unit 2 year 1

Week of lactation	Yield (l/day)	Silage (kg)	Parlour concentrate (kg)	Blended concentrate (kg)	Grainbeet (kg)
1-16	31	33	3.5	4.4	8.6
17-32	23	36	2.5	3.1	4.1
33-44	14	39	0.5	0	1.2
dry	0	25	0	0	0
Estimated ration from group intakes		40	2.5	4	15

A.9 Feedbyte predicted ration required by stage of lactation (average herd yield 8250l) for comparison with the ration fed to Unit 2 year 2

Week of lactation	Yield (l/day)	Silage (kg)	Parlour concentrate (kg)	Blended concentrate (kg)	Grainbeet (kg)
1-16	34	14.3	3.0	3.0	27.0
17-32	27	33.0	2.0	2.1	12.0
33-44	16	37.0	0.5	0	9
dry	0	25.1	0	0	0
Estimated ration from group intakes		35	3	4	10

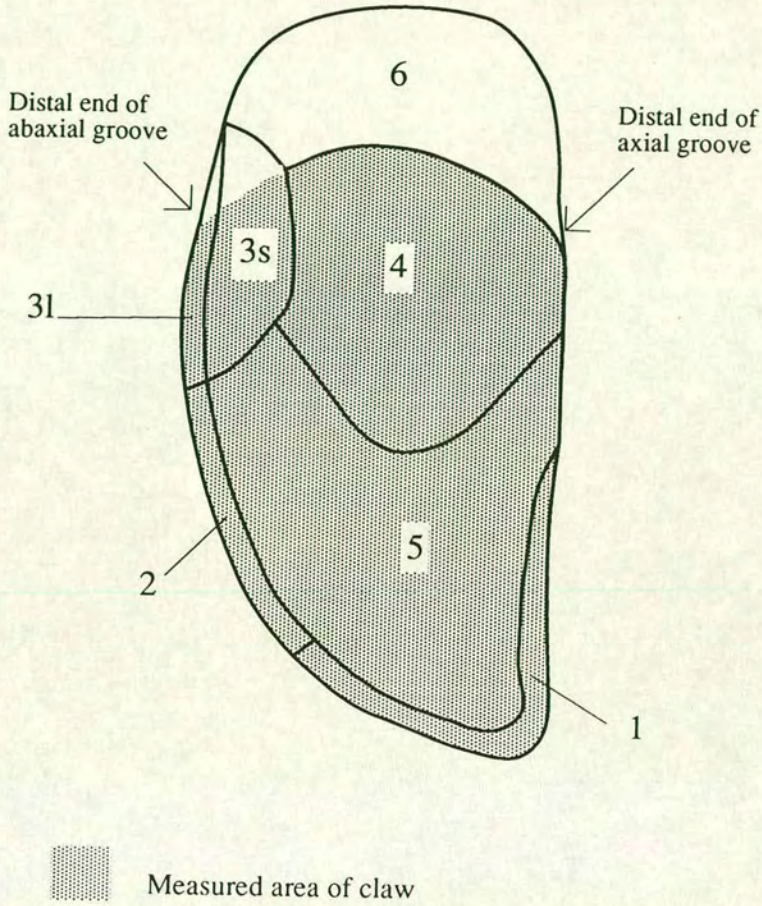
To compare with other Scottish farms, various input and output parameters from the Acrehead farm reports for both years were contrasted against other available farm data (Anon, 1995; 1996).

A.10 Contrast between the Acrehead herds and other Scottish farms*

	1994-95			1995-96		
Parameter	Unit 1	Unit 2	Scottish farms (n=200)	Unit 1	Unit 2	Scottish farms (n=200)
Milk sales l/cow	5399	6936	5808	5503	8451	6003
% Butterfat	4.12	3.40	3.94	4.08	4.11	4.02
% Milk Protein	3.35	3.42	3.39	3.16	3.33	3.29
Concentrates (kg/cow)	485	1525	1287	385	1943	1279
Concentrate use (kg conc/l)	0.09	0.22	0.22	0.07	0.23	0.21

* sources (Anon, 1995; 1996; Bax, 1995; Leach, 1996)

Fig A.1 Hoof map areas, adapted from definitions from the 6th international symposium on diseases of the ruminant digit, Liverpool 1990



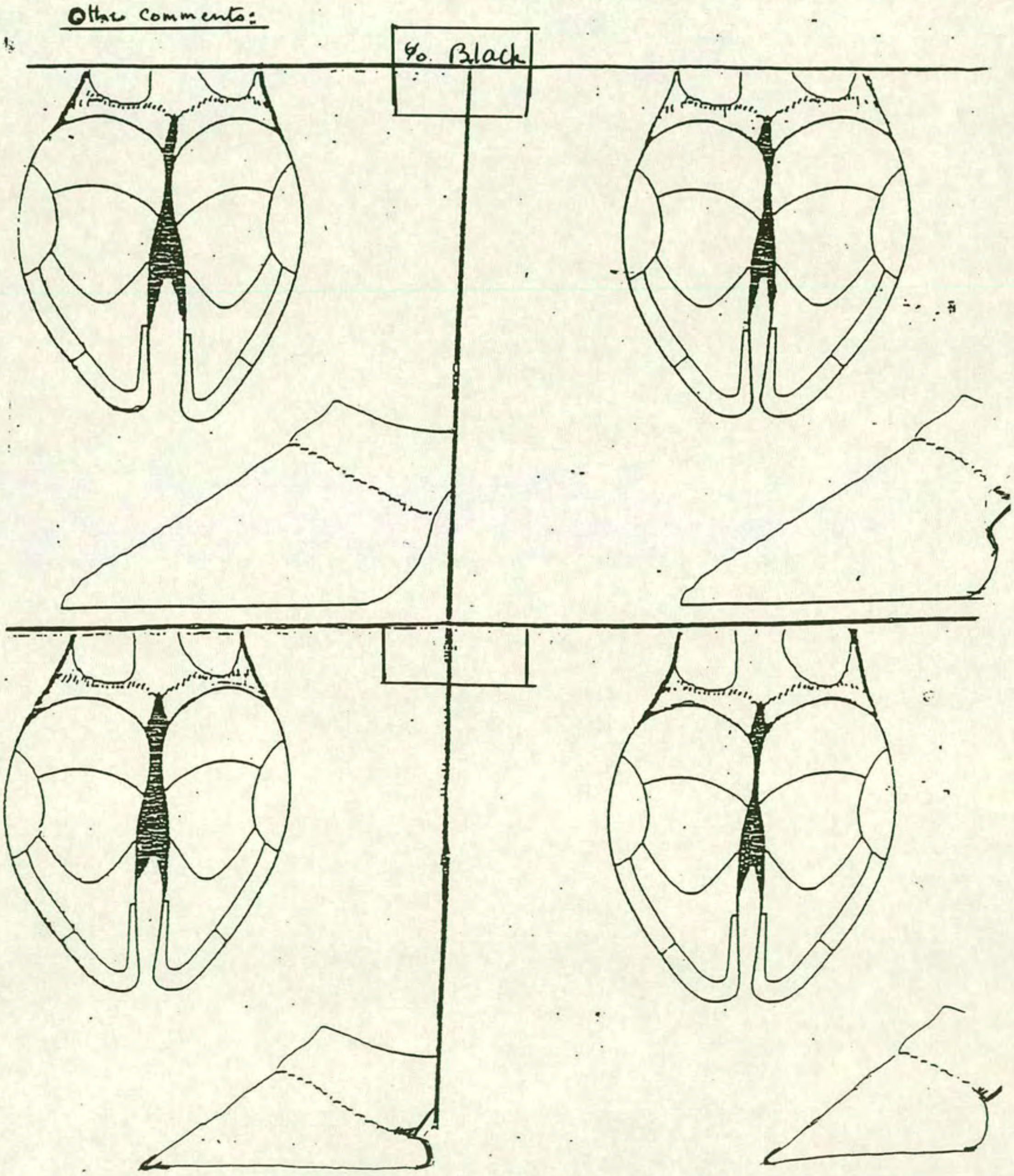
Key: 1 White line at toe; 2 Abaxial white line; 3s Abaxial sole/bulb junction; 3l Abaxial white line adjacent to abaxial groove; 4 Sole/bulb junction; 5 Apex of sole; 6 Bulb of heel.

Fig A.2 Hoof examination data collection sheet

Cow No: Date: L-Score:

Measurements	PM	MT	Hardness				
			Bulb	1	2	3	Wall
Ao							
Ai							
Lo							
Li							

Other comments:



Hoof measurement and lesion data

Table A.11 Effect of treatment on the mean angle of the outer claw in each Examination period

		Angle of outer claw (deg.)			Angle of inner claw (deg.)		
Examination period	Mean weeks post calving	Unit 1	Unit 2	p	Unit 1	Unit 2	p
1	-14	49.1 (0.9)	48.3 (1.0)	0.84	46.6 (0.6)	46.3 (0.6)	0.64
2	-6	50.4 (1.2)	47.1 (1.2)	0.07	48.4 (1.3)	46.7 (1.2)	0.34
3	0	51.0 (0.8)	50.0 (0.9)	0.34	47.7 (0.8)	46.8 (0.7)	0.15
4	7	52.1 (1.0)	53.7 (0.7)	0.29	48.9 (0.9)	49.0 (0.7)	0.73
5	18	51.4 (0.5)	51.6 (0.7)	0.39	48.5 (0.6)	48.1 (0.9)	0.86
6	26	51.6 (1.0)	53.1 (0.8)	0.62	48.9 (0.8)	50.3 (0.9)	0.77

(Standard errors are shown in brackets)

Table A.12. Effect of treatment on median DD score in each examination period

Examination period	Weeks post calving	Unit 1 median	Unit 2 median	p
1	-14	0.0	0.0	0.90
2	-6	0.0	0.0	0.95
3	0.2	0.0	0.0	0.73
4	7	0.0	0.0	0.96
5	18	0.0	0.0	0.36
6	26	0.0	0.0	0.27

Table A.13. Comparison of outer and inner claw length between treatments

		Length of outer claw (mm.)			Length of inner claw (mm)		
Examination period	mean weeks post calving	Unit 1	Unit 2	p	Unit 1	Unit 2	p
1	-14	79.3	78.1	0.26	78.7	77.6	0.22
		(1.28)	(1.1)		(1.1)	(1.1)	
2	-6	78.4	79.1	0.75	77.7	77.8	0.99
		(0.9)	(1.2)		(0.9)	(0.8)	
3	0.2	77.6	78.2	0.61	77.9	77.2	0.52
		(0.7)	(1.0)		(0.7)	(1.0)	
4	7	76.5	76.7	0.88	76.3	76.2	0.84
		(0.7)	(0.9)		(0.7)	(0.9)	
5	18	77.0	77.4	0.12	76.3	76.1	0.12
		(0.7)	(1.2)		(0.7)	(1.1)	
6	26	77.3	78.8	0.82	76.1	74.2	0.20
		(1.0)	(1.1)		(0.9)	(2.1)	

(Standard errors are shown in brackets)

Table A.14 Effect of calving season upon median IDD score

Examination period	Weeks post calving	Autumn calvers	Spring calvers	p
1	-14	0.0	0.0	0.07
2	-6	0.0	0.0	0.14
3	0.2	0.0	0.0	0.09
4	7	1.0	0.0	0.34
5	18	1.0	0.0	0.42
6	26	1.0	0.0	0.18

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Relationship between hoof lesions and the behaviour of cubicle housed Holstein-Friesian cows

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Introduction: Behaviour is considered to be a risk factor in the development of lameness in dairy cows. A reduction in lying time post calving is considered to be a contributing factor to the rise in subclinical claw lesions post calving. If lying time is one component of an animals' activity budget, then standing must also be important. The relationship between standing and lying behaviours and the incidence of hoof lesions and other conditions were investigated.

Methods: The study was conducted over the winter housing period in 2 herds of cows of similar genetic merit in identical housing systems. Records of behaviour and lesion development from 52 animals (32 first parity and 20 second parity) were made at specified examination periods in relation to the calving i.e. -2, -1, 0, 2, 4 and 6 months postcalving. All animals' feet were lifted at the defined examination periods and any heel erosion, infectious disease and claw horn lesions present were scored (Leach *et al*, 1998). Behavioural records of 24 hour activity were made using a scan sampling technique. The behavioural and lesion data was analysed in two ways- i) Direct comparison. Spearman rank correlations; ii) Multivariate: factor analysis was used to generate factor scores which described the interrelationship between behavioural variables for each animal. These scores were then be correlated with lesion score.

Results: Standing within the cubicle area were negatively correlated with both front foot and total lesion score in the precalving (-2 months) and again during the postcalving period 4 (2 months) when peak lesion incidence typically occurs ($r=-0.4$, $P<0.01$). Displacements from the feed face were positively correlated with front foot lesion score ($r=0.57$, $p<0.001$). Total time spent lying time had no significant relationship with hoof lesions in any examination period($p>0.10$). Initial factor analysis revealed 3 factors which scored heavily for the following behaviours: Factor 1 loaded heavily for standing idle in the cubicle and negatively for lying ruminating; Factor 2 loaded heavily for standing behaviours performed in the passageways; Finally factor 3 loaded heavily for standing feeding and negatively for lying inactive. Factor 1 was significantly negatively correlated with heel erosion and infectious foot diseases ($r \geq -0.3$, $p<0.01$) Factor three was correlated significantly positively with front inner score and negatively with hind claw score ($r \geq 0.3$ $p<0.01$). Factor 2 was not significantly associated with any lesions ($p>0.10$).

Discussion: Behaviours associated with standing in the cubicle were significantly correlated with the absence of front foot lesions and infectious foot diseases. During this study, cows stood by placing only their front feet in the cubicle. Removing the front feet from slurry contact or placing them on a sawdust covered surface appears to promote claw health for these feet. The amount of time a cow stood in a cubicle varied widely between individuals, appearing to be a personality or temperament related trait rather than a behaviour affected by herd and production factors. Neither standing behaviour in the passageway nor lying time had any significant relationship with overall foot lesions. Animals with high feeding times and low lying times had a significantly higher degree of front foot lesions and paradoxically a lower amount of hindfoot lesions. Feeding may place higher stresses on the front feet or be associated with more traumatic damage that occurs when an individual is displaced by another cow. We suggest that there is a distinct separation between the behavioural risk factors associated with the fore feet compared to the hindfeet. Since front foot lesions occurred at a significantly lower incidence than hindfoot lesions, we also suggest that the effects of behaviour upon the overall amount of claw horn lesions and other diseases is less important than other risk factors associated with housing and calving in these herds.

References: Leach, K.A., Logue, D.N., Randall, J.M. & Kempson, S.A. (1998). *The Veterinary Journal* **155:** 91-102.

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Subclinical hoof lesions and their significance for lying down behaviour in housed dairy cows

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Introduction. On pasture cows are able to move from standing to lying postures with ease. In contrast during housing the dairy animal is expected to lie within a defined, artificial lying area. From earlier studies in young cows on this experimental farm it was shown that locomotion score was not strongly related to individual lesion score, possibly due to animals adapting their gait to minimise pain. It was hypothesised that during lying down a cow would not be able to compensate adequately and there would be differences in the lying down behaviour for cows with more severe subclinical lesions.

Methods. Video observation of 45 Holstein Friesian cows housed in a cubicle system was conducted in February '96. Animals consisted of an roughly equal mixture of first and second parity animals which were split into autumn and spring calving seasons. Cameras were positioned so that 70% of all cubicles in the cubicle house could be observed. 4 consecutive 24 hour video recordings were made and the following parameters taken off these tapes:

Preparatory phase:- time from selecting a cubicle by placing the front feet in the cubicle, lowering the head under the headrail and the initiation of the first lowering leg movements.

Lying phase- time from first lowering of forelegs and haunches to become fully recumbent

Total time to lie- sum of preparatory and lying phases.

Time to rise- time to move from a recumbent position to become fully standing.

Length of lying bout- total time from becoming recumbent to rising again.

Results. Autumn calving animals had significantly longer lying bouts compared to spring calvers (85 vs 66 min, sem=5.5 , $p<0.01$). There were no significant effects of calving season on lengths of preparatory or lying phases nor mean rising time. Spearman rank correlations revealed that scores for lesions within the claw were not significantly associated with any of the above lying down behavioural parameters. However digital dermatitis (DD) and interdigital dermatitis (IDD) scores had a significant negative relationship with the lying down behaviours and a positive relationship with the length of the lying bout (Table 1).

Table 1. Spearman rank correlations between DD and IDD scores and lying behaviour

	Preparatory phase	lying phase	Total time to lie	Length of lying bout
DD score	ns	-0.31*	ns	0.34*
IDD score	-0.36**	-0.39**	-0.42**	ns

(*=p<0.05, **=p<0.01)

If both DD and IDD scores are combined to form an infectious disease score, then this score was significantly negatively regressed with total time to lie (r^2=0.12, p=0.02).

Discussion. Spring calvers had significantly shorter lying bouts at this time. The metabolic demand experienced by autumn calvers was considerably lower than that of spring calvers as the latter group were at the point of or were approaching peak yeild which necessitated them to increase feeding time and reduce their lying time. Infectious foot diseases were negatively correlated with the length of the lying down phase and positively with length of lying bout. Therefore an afflicted animal appears to make a concious effort to reduce pain. In conclusion the evidence suggests that infectious foot diseases were more painful than lesions associated with claw horn disruption for animals attempting to lie down.

Effect of high and low production regimes on the development of claw lesions and behaviour of dairy cows.

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Intensive production regimes have been implicated in increasing the risk of lameness by placing increased metabolic demands on the animal. If the dairy animal is fed a bulky silage diet , by increasing production the animal is forced to meet metabolic demands which often conflicts with her motivation to rest, leading to the animal being chronically tired and having to stand for increased periods on concrete, increasing the risk of lameness..

Two mixed cohorts of first and second lactation Holstein Freisian cows housed identically were used Low input cohort- 14 animals fed a draff/grass clover silage complete mix plus 0.36 tonnes concentrate during lactation; milked twice daily.

High input cohort- 16 animals fed a draff/grass silage mix plus 1.9 tonnes concentrate during lactation ; milked three times daily.

Feet of all animals were examined at -2, -1, 0, 1 and 2 months postcalving , all feet were scored for incidence and severity of hoof horn lesions and other lameness diseases.

Behaviour watches were conducted fortnightly starting at housing roughly 2 weeks before calving to obtain 24 hour records of lying, feeding and standing duration.

There was no significant differences in hoof lesion score between cohorts however months post calving had a significant covariate effect. Distinct differences in 24 hour activity were observed post calving as low input cohorts fed for longer and lay for significantly less time than high input animals, apparently sacrificing lying time to increase time spent feeding.

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Is milk production hard work for dairy cows?

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It has been suggested that intensive milk production relying on bulky silage-based diets, can lead to metabolic and physical exhaustion as the dairy cow attempts to satisfy high metabolic demands which conflict with her motivation to rest. This study investigated this proposition by assessing the influence of changes in production and management during the housing period on the time budgets of autumn calving Holstein Friesian heifers. In year 1 animals were fed grass silage and milked twice daily. Eight animals were studied in each of 2 cohorts: cohort I was fed 0.5t concentrates with a mean yield of 5720lt; cohort II was fed 1.5t concentrates with a yield of 8453lt. In year 2, animals were housed in the same conditions but management was changed to increase production: cohort III (9 animals) was fed grass clover silage, draff and 0.36t concentrate, milked twice daily, mean yield 6162lt; cohort IV (10 animals) was fed grass silage, draff and 1.9t concentrate, milked thrice daily, mean yield 9309lt.

Activity was recorded in 6 watches of 24 hours, every 2 weeks, starting 6 to 8 weeks post calving until turnout. Lying times were shorter in year 2 than year 1 (11.4 vs. 13.7h, sem=0.34; P=0.01) but did not differ between cohorts in the same year. Feeding time was greater in year 2 but not significantly so (4.6 vs. 4.3h, sem=0.28; P=0.24), cohorts I and II (year 1) did not differ significantly but cohort III (year 2) spent significantly longer feeding than cohort IV (4.9h vs. 4.4h; P=0.02). Overall feeding time was negatively correlated with time spent lying inactive (r=0.15; P=0.025) but not with time lying ruminating. Increased production was associated with reduced lying time without a significant corresponding rise in feeding time; however, the negative association between time feeding and lying inactive suggests animals that fed for longer sacrificed lying time. Increased production between years affected activity budgets by decreasing lying time and this may be linked to increased feeding time. However results are inconclusive as the animals on a lower plane of nutrition may have been working as hard as animals on the higher input/higher output regime, meeting metabolic demand by feeding for longer on a less energy dense diet and possibly drawing on body reserves to a greater extent.